3 5556 020 334 124

TRANSIT ROLLING STOCK REPLACEMENT STUDY

JULY 1978

POLICY PAPER 1978-8

Dilip R. Jhaveri

Regional Transportation Authority

Chicago, Illinois

"The preparation of this report has been financed in part through a grant from the U. S. Department of Transportation, Urban Mass Transportation Administration, under the Urban Mass Transportation Act of 1964, as amended"

T12m3
HE
4321
T772

ACKNOWLEDGEMENT

Significant contributions are acknowledged by many individuals of the RTA, the CTA and the commuter railroads who made the Rolling Stock Replacement Study possible. Specifically, Dr. Aadel ElDib, of the RTA's Systems Department introduced me to Posner's article, "Life Cycle Costing with a Discount Rate" and gave invaluable encouragement in the early phase of the project. Steve Wojtkiewicz, also of the Systems Department, prepared the computer program. Special thanks are due to Joanne Vlecides and Howard Permut of Development Planning for their continued and active support and interest in the project. Douglas O'Brian of Development Planning made a taxing effort to collect data on locomotive and coach maintenance, especially during the cold winter months of 1977.

William Perkins and Richard Corrin of the RTA's Transportation Department provided valuable assistance and support in collecting and interpreting bus and locomotive-coach maintenance data. Without their personal interest this project could not have been completed.

The contribution and cooperation of Howard Benn and John Gaul of the CTA's Operations Planning Department have been important in coordinating the replacement study efforts of the two agencies. The CTA also provided access to its files, and maintenance procedures and workshops.

The Milwaukee Road and the Burlington Northern provided valuable help in understanding their maintenance system and allowing us to monitor their maintenance activities for nearly 5 months in 1977.

Special thanks are extended to Dr. Daphne Christensen in giving encouragement and assistance in the organization and completion of this study, and to Jack Meltzer, Director, Division of Program and Planning for making this arrangement possible. Russell Porter is credited with the typing of this report.

Dilip R. Jhaveri, Manager
Rolling Stock Replacement Study
Regional Transportation Authority
Chicago, Illinois 60610

August, 1978

C O N T E N T S

1. INTRODUCTION

a. Statement of the Problem

b. Objectives of this Study

c. Background and Scope of Research

d. Contents of this Report

2. CRITERIA FOR ROLLING STOCK REPLACEMENT

a. Service

b. Economy

c. Technology

3. LIFE CYCLE COST ANALYSIS

a. Basic Concepts

b. Computation of Life Cycle Costs

c. History of Life Cycle Cost Analysis

d. Replacement/Rebuilding Decisions Using LCC Analysis

4. REPLACEMENT ANALYSIS OF RTA BUSES

a. Transit Bus Cost

i. Maintenance Cost
ii. Reliability Cost
iii. Depreciation Cost
iv. Special Appreciation
v. Annual and Cumulative Average Per Mile Costs
vi. Average Cost Under Increasing Prices

b. Optimum Bus Replacement

i Cost Increase Equal to Discount Rate
ii. Discount Rate of 3.2 Percent and More
iii. Cost Increase of 5.0 Percent
iv. Output Level and Optimum Replacement

c. Summary of Results and Conclusion

CONTENTS (Continued)

5. REPLACEMENT ANALYSIS OF COMMUTER RAIL LOCOMOTIVES

a. Commuter Rail Locomotive Costs

i. The Maintenance Cost Survey
ii. Depreciation Cost
iii. Reliability Cost
iv. Average Cost

b. Commuter Rail Locomotive Replacement

i. Cost Increase Equal to Discount Rate
ii. Discount Rate of 3.2 Percent and More
iii. Cost Increase of 5.0 Percent or More
iv. Effect of Sudden Price Increase

c. Summary of Results and Conclusion--Locomotive Replacement

6. FUTURE WORK IN LCC REPLACEMENT ANALYSIS

APPENDIXES

I. Computer Program for LCC Replacement Analysis

II. Annual Variable Costs of Transit Bus by Annual Miles and Rates of Real Cost Increase

III. Locomotive Maintenance Survey Form

L I S T O F T A B L E S

1.1 Age of Transit Rolling Stock in Northeastern Illinois in 1976

3.1 Decision-Making on Extraordinary Maintenance vs. Replacement

4.1 Per Mile Repair and Maintenance Cost of Selected RTA Buses and Carriers by Bus Life Miles

4.2 Road Call Rates of Selected RTA Buses and Carriers by Bus Life Miles, July thru December, 1977

4.3 Annual Miles, Maintenance, Depreciation, Reliability and Total Cost for RTA's Suburban Transit Buses

4.4 Minimum Average Per Mile Cost for Transit Bus Under Increasing Real Costs by Life Miles and Years

4.5 Optimum Replacement Miles and Years for Transit Bus by Level of Use, Rates of Cost Increase and Initial Purchase Price

4.6 Life Cycle Cost Increments for Transit Bus by Use Level, Life Miles and Age in Years - Net Discount Rate of 10 percent Annually

4.7 Life Cycle Cost Increments for Transit Bus by Use Level, Life Miles and Age in Years - Real Cost Increase of 5 Percent Annually

4.8 Per Mile LCC Increments by Constant Annual Outputs Relative to a Declining Rate of Output

5.1 Locomotive Calculated Repair Cost Including Unscheduled Maintenance

5.2 Annual Miles, Maintenance, Depreciation, Reliability and Total Cost of Commuter Rail Locomotives

5.3 Life Cycle Increments for Commuter Rail Locomotives by Annual Rates of Price Increase

L I S T O F F I G U R E S

3.1 Average Cost Curve as Sum of Maintenance and Depreciation Cost Curves

3.2 Minimum Average Cost Replacement Cycles

3.3 Uniform Continuous Equivalent Costs

3.4 Life Cycle Cost Increment and Discount Rate

3.5 Life Cycle Cost as Function of System Reliability

3.6 Basic Concepts of Decision-Making on Extraordinary Expense Using Life Cycle Cost Analysis Approach

4.1 Maintenance and Repair Cost Per Mile and Total Transit Bus Miles

4.2 Fuel Cost Per Mile and Total Transit Bus Miles

4.3 Road Call Rates and Total Transit Bus Miles

4.4. Life Cycle Cost Increments by Replacement Miles and Annual Miles for Transit Bus at Annual Discount Rate of 10 Percent

4.5 Life Cycle Cost Increments Under Increasing Real Costs by Annual Outputs

1. INTRODUCTION

a. Statement of the Problem:

The expenditure for procurement of transit rolling stock- buses, locomotives and coaches - is an important component of the capital requirement of public transit agencies. The age of equipment significantly determines the customer comfort, reliability of operations and maintenance expenditure. In the absence of government financial assistance, comfort and reliability were sacrificed and outdated transit equipment was often maintained at relatively high cost.

The long lead time necessary for the procurement of rolling stock requires advance planning and federal capital grants approval. One of the objectives and a requirement of the 1974 Act establishing the Regional Transportation Authority in Northeastern Illinois is to plan annually for the capital need of the transit agencies for the next five years. Capital improvement programs must be based on available funds as well as economic evaluation of competing projects.

According to a 1974 study of the transit operations in the Northeastern Illinois by Simpson and Curtin, the average age of CTA buses in 1976 was 8.6 years and that of other bus operators was 14.8 years (1). Table 1-1 presents a summary of age of rolling stock of the region's transit system in 1976. Acquisitions and retirements since 1974 are not accounted for. The age summary is indicative of the substantial need for replacement of most of the rolling stock items.

TABLE 1-1

AGE OF TRANSIT ROLLING STOCK IN NORTHEASTERN ILLINOIS IN 1976

Age in Years	Transit Operator: CTA Buses	Rapid Transit	Sub. Bus	Sub. Trains: Coaches	Sub. Trains: Locomotives @
0-1	-	-			
2	-	-	Less than 4 years	Less than 3 years	
3	50	-	91	661	
4	50	-			
5	-	-			
6	-	150	4 to 8 years		
7	50	-	77		
8	42	-			
9	150	-	More than 9 years		
10 or more	2,102	949	276	190	
TOTAL	2,444	1,099	444	851	127
Average Age in Years	8.6	21.1	14.8	19.6	18.7

---

* Based on Public Transportation Systems in Northeastern Illinois, Summary, by Simpson and Curtin, January, 1975. The study was prepared for the Regional Transportation Authority (RTA)

@ Some were rebuilt in recent years. Most are older than 10 years.

b. Objectives of this Report:

The objective of this report is to present the findings of a research study to develop rational basis for replacement, rebuilding and procurement of rolling stock - buses, locomotives and coaches - by the Northeastern Illinois Regional Transportation Authority (RTA).

This study examines various criteria for decision and presents Life Cycle Cost (LCC) analysis as the most appropriate approach to determine economic life span of equipment, select least cost bids, decide between rebuilding and new purchase, and equipment management to minimize per mile cost. The philosophy as well as the mechanics of LCC for replacement analysis of transit rolling stock are presented.

The LCC approach is applied to current transit buses, diesel electric suburban service locomotives and coaches using available data on cost of procurement, maintenance, reliability and depreciation and factors contributing to higher operating expenditure attributed to age of equipment. Because of limited data for locomotives and coaches, the present study uses the manufacturer's simulated cost data for locomotives and the analysis of replacement life of coaches is deferred until some future date when basic data on costs are available.

With the assistance of good quality suburban bus maintenance data which the RTA has collected in the second half of 1977, this report demonstrates the applicability of LCC analysis to a variety of rolling stock management problems, such as output level, replacement interval, and economic evaluation of major repairs.

This study provides a groundwork for systematic data collection for various cost components of rolling stock and furnishes an analytical framework to employ extensive data banks for fleet management decisions.

c. Background and Scope of Research:

The transit Rolling Stock Replacement Study was included in the Unified Regional Planning program for the Chicago Metropolitan Region for Fiscal Year 1977. The mission of the study was development of an analytical framework to support policy decisions on the question of when to repair or replace an item of rolling stock. The study proposal placed significant emphasis on minimizing life time cost of operating and owning the vehicles. This initial study proposal assumed availability of life time cost of transit vehicles. The project was allocated $75,000 of which $50,000 were given to the CTA for CTA buses and rapid transit cars analysis, the remaining $25,000 to the RTA for RTA buses, locomotives and suburban coaches.

In the second half of 1976, the RTA contacted some of the carriers, including the CTA, suburban bus operators and railroads to determine the availability of vehicle histories, costs of maintenance, efficiency of vehicles over time and similar information for constructing life time cost of current rolling stock inventory. It was soon realized that such data are practically non-existent. A variety of vehicles and different models inhibit construction of life time cost tables at this time. A concerted effort to develop a uniform data base must precede the task of construction of replacement schedules. The need for a rational policy for

orderly replacement of rolling stock is indicated by this lack of basic statistics.

In August of 1977, the RTA instituted a limited survey of maintenance of locomotives and coaches at the Burlington Northern and Milwaukee Road shops. The survey yielded five (5) months of maintenance history and an understanding of record keeping by the railroads. For various reasons, decribed later, it was found impractical to construct cost schedules of locomotives from this survey. Present record keeping of the railroads did not permit a survey of maintenance of coaches. For RTA's approximately 500 suburban buses, a detailed vehicle maintenance reporting system was installed in June 1977. This information system provides a detailed cost account for every bus, including mileage. A six month summary of bus costs from July through December, 1977 is the basis for the present study. ~~In addition~~, the CTA's regular publication "Vehicle Series Cost Report" gives per mile maintenance cost by bus vehicle series for each of the 13 four-week periods a year for the CTA's 2500 buses. Increasing cost of maintenance with age is quite apparent from these records. Since suburban bus fleets and maintenance practices differ significantly from the CTA, the present study uses the suburban RTA bus data only. Further, cost data for individual CTA buses are not available.

Compared with the original intentions, the present study is limited by lack of a cost history of vehicles. Even if general cost data were available, a comprehensive study of each vehicle and specific policy formulation are beyond the scope of the present effort for the time and cost involved. Further, there are always

non-quantifiable objectives and constraints that must be accounted for in replacement decisions.

The present study makes a valuable contribution in defining the methodology for addressing the vehicle management problems and demonstrates the versatility of LCC approach in decision making. The results of this demonstration effort are subject to revision as more reliable, factual data on vehicle costs become available.

d. Contents of this Report:

This report examines various criteria affecting rolling stock replacement/rebuilding decisions of the public transit industry, and suggests the life cycle cost analysis as the most valuable tool for transit management. These criteria are examined in Chapter 2. Various components of life cycle cost of rolling stock are reviewed. Only major costs that are affected by use or length of ownership are included, such as procurement cost, reliability cost, depreciation, maintenance, and fuel consumption.

The basic concept of life cycle cost analysis, a review of existing literature on the subject and important applications are presented in Chapter 3.

Optimum life analysis of buses and locomotives is presented in Chapters 4 and 5 respectively. In each case, the life cycle cost of vehicles are presented with various assumptions on discount rate, depreciation schedule, maintenance cost increase, and efficien decline with age. A range of optimum vehicle life is presented base on some plausible assumptions on increase in real costs of maintenan price of replacement vehicle, fuel, and the quality and reliability of service, subject to further refinements.

Chapter 6 outlines the future work in replacement analysis using LCC approach. Development of cost information oriented to each vehicle and per mile output cost related to vehicle age is emphasized for making better replacement/rebuilding decisions.

2. CRITERIA FOR ROLLING STOCK REPLACEMENT

The "optimum replacement policy" refers to the life of rolling stock equipment for which an average, per mile cost of operation, maintenance and depreciation in constant dollars, is minimum. Ideally, costs should include not just financial cost but also the qualitative aspects of the service. The present analysis is concerned primarily with monetary costs and assumes a decent level of reliable service. The following examines service, economic and technological aspects of transit rolling stock.

a. Service

With reference to the transit industry, service means the comfort and quality of ride in the vehicle, as well as the reliability--the avaibility of equipment, on-time arrivals and departures, and frequency of breakdowns during service. Beyond certain age and a minimum level of maintenance, vehicles may show signs of deterioration and dilapidation which could adversely affect ridership, increase customer complaints, and frequency of road calls to service disabled vehicles.

Although there is concensus on need to include service factors mentioned earlier in determining the optimum replacement policy for transit rolling stock, measuring the qualitative service aspects remains difficult. Except in extreme cases, translating visual and comfort aspects as well as cost of delays into dollars and cents is not possible. Attempts to value delays are likely to suggest excessively high reliability.

Most railroads in the Chicago region, for instance, received on-time premium from the RTA of $2,000 each month for every full percent point above the established limits: 90% for the Burlington Northern, the Milwaukee Road, and the Chicago and Northwestern Railroads, and 93%for the Illinois Central Gulf. A more sophisticated approach is needed to include reliability as a base for maintenance and replacement decisions.

In the present analysis, the road call cost of buses has been used as an indicator of reliability cost since it is closely related to age of buses and is the direct cost of unreliable equipment. (2) An average cost of $30 per road call was assigned. A similar cost assignment of delay cost on railroads could be developed with better monitoring of cost of rail operation.

b. Economy

Since financial resources available to a transit authority are limited, minimizing the life-cycle cost per mile becomes a strong management objective, so long as a certain minimum reliability level is maintained. Economic factors include items of cash outlays required to acquire, maintain and operate transit vehicles. Defining these costs in a consistent manner and collecting the information for a system as large as the RTA is complex and expensive though a rewarding task. Existance of numerous carriers and a variety of vehicles make the maintenance information system difficult to implement.

Acquisition costs include cost of preparing specification, selecting bids and other management expenses in buying the rolling stock, purchase price and interest payments. In most instances, the overhead costs of acquisition are not separately defined for each vehicle.

Depreciation cost is the annual decline in the market value of rolling stock. As a rule, the decline is the steepest in initial years. The unique problem with public transit vehicles is the absence of effective, competitive, or secondary market. Further, the transit authorities use the rolling stock to a point where the equipment is worth merely scrap value--for lack of funds for equipment replacement. Consequently, there is little experience in determining depreciation. Assuming that a vehicle becomes almost worthless at the end of its service life, we must assume total depreciation at that point. Several hypothetical depreciation functions will be tried and examined in terms of their effect on optimum replacement policy(3). Depreciation experience of related equipment will also bear upon test results. For instance, the RTA recently acquired C&NW locomotives and coaches. The purchase price of these vehicles may serve as a guide.

The Maintenance cost of rolling stock and the level of maintenance, i.e. the expenditure per mile, determines significantly the quality of the fleet, as well as the optimum replacement age. The quality of the original equipment, punishment during service, preventive maintenance, labor rates and productivity define the maintenance cost of vehicles. Labor cost constitutes the largest segment of this cost category.

Since overhead facilities, such as garages are needed, irrespective of age of rolling stock, they are excluded from LCC computation, though, it is realized that per mile overhead cost of very old equipment would be higher than for a very new one. The minimum life cycle cost replacement policy is determined only by the marginal or incremental cost. Fixed costs do not affect the optimum life span, though the size of average cost increases.

For the purpose of this analysis, overhaul and rebuilding are essentially special maintenance. However, the special maintenance cost may be capitalized and depreciated over a resonable time period rather than assigning it entirely to the year of expenditure.

Fuel costs under "optimum" operating situations are invariant to vehicle life. It is known, however, that older equipment give lower mileage than newer ones.
At 50¢ a gallon and 30,000 miles a year, a transit bus will use $3,750 worth of fuel a year at 4 miles per gallon.
If the engine and other equipment deteriorations reduce the mileage to 3.5 per gallon, the annual cost is $4,286, an increase of $536. A six month survey of fuel consumption of RTA buses does not indicate higher fuel consumption for older buses. Since older buses are not air-conditioned and differ technicallly from the new ones, the efficiency comparison is not always valid. The present study relies on CTA fuel consumption data for bus series. Similarly equipped CTA buses do indicate a higher fuel consumption for older buses. Though the pattern is weak, and may not be supported statistically.

Attempts to obtain test results on fuel effiecincy of bus and locomotive engines from the General Motors Corporation have not been successful. Further efforts, therefore, must depend on detail accounting of fuel consumption for each RTA vehicle under normal operating conditions. Efficiency decline, in the range of five to ten percent over life, may be assumed for a well maintained fleet of locomotives and buses until more reliable statistics become available. Increasing consumption of oil and miscellaneous items are ignored for lack of data, as well as their insignificant contribution to total cost.

c. Technology:

These factors include changes in the technology of the vehicles that make the new vehicles superior in terms of energy efficiency, reliability, speed, safety, service, etc. In general, the transit vehicle technology has not changed much in years. The present "New-look" bus of the General Motors introduced in the early 1960's remains the dominant vehicle in the United States transit bus fleet. Although many mechanical and safety innovations have taken place, such as sutomatic transmission and power steering, there is little overall change in the basic vehicle. Even the transbus includes few technological changes that affect replacement decisions. In fact, the new buses are more expensive, heavier, fuel inefficient, and have lower passenger capacity than the present buses. (4)

In suburban rail transit, the most important change is the introduction of bi-level coach that is lighter, and includes more amenities and comfort than the steam-heated, heavy coach it replaced some 15 years ago. The technology of power plant and propulsion of locomotives remains basically unchanged over the past 30-40 years. Like the current buses, the locomotives and coaches in service need not be replaced on technological ground. The life cycle cost analysis presented in this study is an ideal tool to compare technologically different equipment on economic ground.

3. LIFE CYCLE COST (LCC) ANALYSIS

a. Basic Concepts:

An important economic characteristic of transit service is the high operating costs compared with purchase price. A standard transit bus that could be purchased for $75,000 in 1977, costs an average of 43.2 cents for maintenance and 13.06 cents for fuel per mile based on CTA's "Vehicle Series Cost Report". (5) A survey of seven transit properties in 1974 shows annual average cost per mile for bus operations of $1.56. (6) Assuming the 1977 cost of $2.50, the operating cost over 500,000 miles technical life of bus is $1.25 million, more than 16 times the purchase price. Similarly, a $750,000 diesel-electric locomotive with potential service life of a million miles would cost $11 million in operating cost, based on current rates paid to rail carriers by the RTA.

The above figures underline the importance of operating cost in addition to procurement in evaluating replacement versus rebuilding of transit rolling stock. It is also noted that maintenance cost that is directly related to equipment quality and age should be given appropriate attention. The RTA carriers, including the CTA, place more than 100 million bus miles a year. Saving of even one cent a mile in operations cost amounts to a million dollars a year.

Life cycle cost of rolling stock is simply an average per mile cost of operating, maintaining and replacing equipment for a very long time span. Replacement age, however, is to be defined such that the sum of costs is the minimum in terms of discounted present value. The basic assumptions of life cycle cost analysis are (1) maintenance and reliability costs increase over time, (2) depreciation, the annual decline in market value, is high during early years but less in later years, and (3) the discount rate, the time value of money is always positive. Figure 3.1 graphically illustrates the average cost curve as the sum of maintenance and depreciation cost curves.

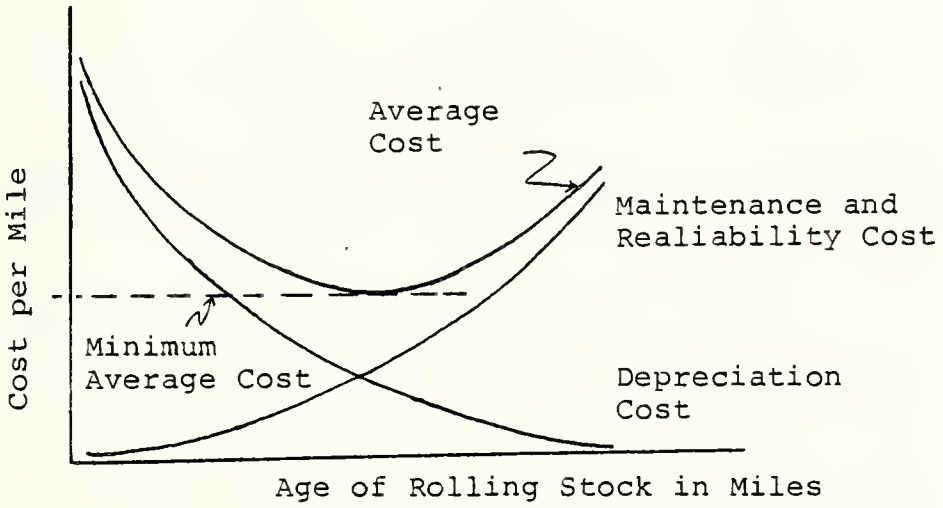


Figure 3.1: Average Cost Curve as Sum of Maintenance and Depreciation Cost Curves

The usual average curve is U-shaped and has a minimum so long as maintenance and depreciation functions are well-behaved. If equipment is replaced at the point of minimum average cost (T), a series of curves can be developed showing the replacement cycles as in Figure 3.2.

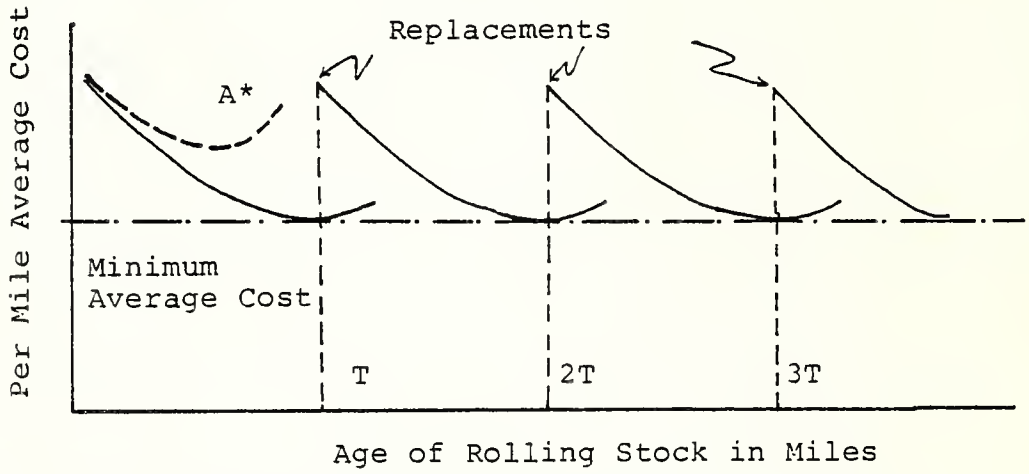


Figure 3.2: Minimum Average Cost Replacement Cycles

Implicit in the replacement policy is a decision to postpone purchasing cost while incurring higher maintenance and reliability costs. The postponement, however, generates savings at a rate of return equal to alternative investment opportunities. For a public agency, the decision of not purchasing a vehicle means investment in other sectors of the economy, or even reducing taxes. Therefore, the discount rate for a transit agency is the so called social discount rate, or the rate of social opportunity cost. The real gross national product (GNP) of the United States increased at an annual compounded rate of 3.2 percent between 1960 and 1975, compared with a rate of 2.0 percent from 1970 to 1975.

The lower rate of growth in the later years reflects the economic recession in 1974 and 1975 when the real GNP actually declined by 1.7 and 1.8 percent, respectively. For the purpose of the present analysis, a long-term growth rate of 3.2 percent is used as a discount rate.

Most studies of life cycle cost assume a life span of equipment or structure. A study of transit buses by the Advanced Management Systems, Inc., for instance, assumes bus life of 600,000 miles. (7) A comparison of competing buses then depends on maintenance and operation expenses and current purchase price over a predetermined life span. The General Services Administration (GSA) has taken considerable interest in life cycle costing as a procurement process. (8) The GSA, however, does not consider variable life span of competing products. The life cycle cost analysis approach used in this study determines optimum life span as a function of costs over many procurement cycles. The proposed approach not only allows to compare bids but also to determine whether specific repairs and overhauls at certain age of equipment should be undertaken. Since life span is variable, the approach enables to recalculate the minimum and the maximum periods the repaired vehicle must be used to justify the repair. In addition, the optimum annual miles policy can be formulated with an objective to minimize annual per mile life cycle cost. Replacement cost is often not critical in the LCC analysis of single items with extremely long life span, such as buildings and structures. For rolling stock management, however,

replacement and rebuilding are quite important since a part of the fleet must be continuously rebuilt or replaced. Important question in the LCC analysis are the number of replacement cycles and the time horizon of study. For illustration, consider a span of 15 years for a transit bus analysis. Replacement analysis then computes the cost of replacement and maintenance at various interva to identify the age when LCC is the lowest. If a bus is replaced annually, the depreciation cost is high but maintenance cost is low. On the other hand, a bus replaced after 15 years of service has high total maintenance cost and depreciation cost equal to the cost of initial acquisition, but no replacement cost. Since depreciation cost is high in the initial years of equipment, LCC is found to be the lowest on the 15th year. The study horizon limit of 15 years or even 50 years results in a highly fluctuating LCC curve reflecting the annual variation in costs and inconsistent assignment of replacement cost. Consequently, the procedure of limiting the study horizon is arbitrary, inconsistent and not scientific.

A consistant LCC analysis procedure assumes an infinite, or very long time horizon that smooths out annual cost fluctuations natural to bus operations and allows a comparison of equipment of different life spans and annual costs. When costs are constant over the replacement cycles, or rising less than the discount rate, the present value of future costs is always declining in constant dollars. The declining cost

series can be readily summed for infinite time horizon. For example, an annual cost of one dollar per mile, discounted at 3.2 percent per year to infinity is equivalent to $31.75 in present value. Given the annual maintenance, depreciation, fuel and reliability costs for an average transit bus estimated for the present study, the minimum per mile LCC for a 40,000 miles a year bus is $13.49 at 480,000 life miles if the discount rate is 3.2 percent. In other words, an investment of $13.49 at net return of 3.2 percent (allowing for inflation), finances an annual output of one mile forever, provided that the bus is replaced at 480,000 miles interval.

When costs are increasing at a faster rate than the discount rate, the present value of future costs are infinitely increasing with time. Therefore, a long enough time horizon relative to approximate life span of equipment must be selected to assure a sufficiently large number of replacement cycles, for all replacement intervals examined. It must be emphasized that the purpose of the long time horizon is not to compute the total cost over the many long years, but only to compare replacement intervals on equal terms. For instance, if costs increase at an annual rate of 5.0 percent in constant dollars and the discount rate is 3.2 percent, the minimum average annual per mile LCC over 500 years is $193,726 for a bus used 40,000 miles a year. Note that it is the relative costs at alternative replacement intervals rather than the absolute cost figures over many years are of interest in replacement analysis. The LCC increment curves using long time horizon are U-shaped and have a smoother profile than the single-cycle cost curves.

The next Section will describe the simple mathematical structure of life cycle cost analysis. Computation of LCC is uncomplicated and can be performed manually when costs are not increasing faster than the discount rate. Increasing costs, however, require summation over many time intervals. The computer program presented in Appendix I facilitates LCC computations and allows experimentation with discount rates, inflation factors, and cost fluctuations.

b. Computation of Life Cycle Cost:

The objective of replacement analysis is to determine the procurement time interval T so that the life cycle cost increment -- the total discounted cost per annual mile of future procurements and operations and maintenance costs -- is minimum. Vehicle miles per year being under management control and a readily available index of vehicle utilization, is found most appropriate for measuring costs. For computing present and discounted values of the cost streams, time in years and annual discount rates are important parameters. Annual use of vehicles in miles, therefore, is an appropriate base for cost in life cycle cost analysis of rolling stock.

For simplicity and without compromising study objectives, it is assumed that the units purchased are essentially similar or equivalent to the ones being replaced. All costs including maintenance and operations, are expressed in constant dollars. The long term discount rate is the social opportunity cost of money, usually 2 to 3 percent annually.

If a rolling stock item is procured at an interval T at price P and discount rate α_1, then the total life cycle cost increment, the sum of all future costs, is given by

$$(1) \quad C_{\alpha_1}(T) = \left(\sum_{t=0}^{T} e^{-\alpha_1 t} \cdot M(t) + e^{-\alpha_1 T} \cdot P \right) +$$

$$+ \left(\sum_{t=0}^{T} e^{-2\alpha_1 t} \cdot M(t) + e^{-2\alpha_1 T} \cdot P \right) + \cdots\cdots\cdots$$

$$+ \left(\sum_{t=0}^{T} e^{-n\alpha_1 t} \cdot M(t) + e^{-n\alpha_1 T} \cdot P \right)$$

where $n \to \infty$, or a large number. M(t) is a function of time (t) or an index of use, i.e. miles.

Condensing the series and using the fact that for $\alpha_1 \geq 0$ and $t \geq 0$

$$(2) \quad C_{\alpha_1}(T) = 1/(1-e^{-\alpha_1 T}) \left(\sum_{t=0}^{T} e^{-\alpha_1 t} \cdot M(t) + e^{-\alpha_1 T} \cdot P \right)$$

It should be noted that the term $1/(1-e^{-\alpha_1 T})$ accounts for an infinite number of cycles of replacements and maintenance and its value varies from infinity when T is very small, to one when T is very large. Naturally, if equipment is replaced more frequently, the life cycle cost is higher than if replaced at longer intervals, provided that other costs do not increase.

If maintenance cost M is an increasing function of use (t), as may be generally assumed, equation (2) will show large fluctuatic in LCC since procurement cost is assigned to the replacement year only. Therefore, the price P is substituted by a depreciation function which decreases with use (t). The depreciation cost D(t) of a vehicle at time t is the difference between the market values in the preceeding year (t-1) and the year (t). In the initial years depreciation is high but reduces to almost zero near the end of economic life of equipment. An additional cost of rolling stock operation is the reliability cost R which is a function of equipment age (t) at a specified level of maintenance. The difficulties in measuring this cost have been examined earlier and will be further explored in the following chapters.

The relevant form of life cycle cost equation is

$$(3)\quad C_{\alpha_1}(T) = 1/(1-e^{-\alpha_1 T}) \left(\sum_{t=0}^{T} e^{-\alpha_1 t}.M(t) + \sum_{t=0}^{T} e^{-\alpha_1 t}.D(t) + \right.$$

$$\left. + \sum_{t=0}^{T} e^{-\alpha_1 t}.R(t) \right)$$

where D(t) and R (t) are depreciation and reliability cost functions, respectively, of time or use (t). Other notations are the same as in (1).

So far, no net change in costs have been assumed. What if price P rises over and above the general price level increases? If successive prices of a cost component increase in constant dollars, the discount effect - the savings generated from postponements reduce proportionately. Equation (3) can be redefined as

$$(4)\quad C_{\alpha_1}(T) = 1/(1-e^{(-\alpha_1+\alpha_2)T}) \left(\sum_{t=0}^{T} e^{(-\alpha_1+\alpha_2)t}.M(t) \right) +$$

$$+ 1/(1-e^{(-\alpha_1+\alpha_3)T}) \left(\sum_{t=0}^{T} e^{(-\alpha_1+\alpha_3)t}.D(t) \right) +$$

$$+ 1/(1-e^{(-\alpha_1+\alpha_4)T}) \left(\sum_{t=0}^{T} e^{(-\alpha_1+\alpha_4)t}.R(t) \right)$$

where α_2, α_3 and α_4 represent net growth rate of maintenance, depreciation, and reliability costs, respectively, in constant dollars. Other notations are the same as defined earlier.

Equation (4) assumes that α_1 is greater than α_2, α_3, and α_4. If not, the series is unbounded and increases to infinity. For a more general definition of life cycle cost increment where the long term costs in constant dollars may increase at a faster rate than the long term discount rate, a long time horizon, relative to the technical life of equipment must be specified.

$$(5)\quad C_{\alpha}(T) = \left(1+ \sum_{q=1}^{Q} e^{(-\alpha_1+\alpha_2)qT}\right) \left(\sum_{t=1}^{T} e^{(-\alpha_1+\alpha_2)t}.M(t) \right) +$$

$$+ \left(1+ \sum_{q=1}^{Q} e^{(-\alpha_1+\alpha_3)qT}\right) \left(\sum_{t=1}^{T} e^{(-\alpha_1+\alpha_3)t}.D(t) \right) +$$

$$+ \left(1+ \sum_{q=1}^{Q} e^{(-\alpha_1+\alpha_4)qT}\right) \left(\sum_{t=1}^{T} e^{(-\alpha_1+\alpha_4)t}.R(t) \right) +$$

$$+ \left(e^{(-\alpha_1+\alpha_2)QT}.\left(\sum_{t=1}^{K} e^{(-\alpha_1+\alpha_2)t}.M(t) \right)\right) +$$

$$+ \left(e^{(-\alpha_1+\alpha_3)QT}.\left(\sum_{t=1}^{K} e^{(-\alpha_1+\alpha_3)t}.D(t) \right)\right) +$$

$$+ \left(e^{(-\alpha_1+\alpha_4)QT}.\left(\sum_{t=1}^{K} e^{(-\alpha_1+\alpha_4)t}.R(t) \right)\right)$$

where Q+1 represents the number of replacements and QT+T+K is a constant representing the time horizon. If equipment with different life spans and life cycle costs at various replacement ages are to be examined, Q should be large relative to T, for all values of T. If Q is large, $K \rightarrow 0$ and the last three summation terms may be dropped. Notice that equations (4) and (5) are identical when the long term discount rate is greater than the long term cost rates. It must be emphasized that the objective of replacement analysis is not to determine the total cost over an infinite time horizon, say a thousand years, but only to compute relative values of each replacement age so that the age associated with the lowest life cycle cost increment can be identified.

c. History of Life Cycle Cost Analysis and Transit Vehicle Management:

Life cycle cost analysis as a concept or mathematical formulation is not new or recent. It has been practiced under a variety of names, such as value engineering, cost-in-use, cost effectiveness, discounted cash flow, cost-benefit, etc. It is very likely that most of the effort toward a systematic treatment of long term expense and performance has occured since World War II. The LCC approach has received increasing attention in recent years primarily because of greater cost of fuel and labor in operating and maintaining rolling stock, buildings and similar investments. The emphasis on energy efficient equipment and appliances has created a renewed need to balance higher cost of initial procurement with lower life time cost of operations and maintenance. There has been legislative push at all levels of government to consider total life cost in accepting bids. Most texts in economics and finance now include some treatment of LCC analysis.

John E. Williams provides a detailed history of the LCC analysis in the United States.(9) He notes a significant number of publications by the Federal agencies, especially the General Services Administration (GSA) and the Department of Defense (DOD). The GSA frequently conducts workshops in LCC for procurement training programs.(10)

Energy concerns have also spawned numerous bills within state legislatures that mandate LCC for construction and rental of sizeable properties. Alaska, for instance, passed a law in 1975 which requires LCC procurement of all public facilities. Numerous efforts to legislate LCC are described in detail by Williams.

In the private sector, major corporations are known to use LCC for procurement though documentation of their works remain generally unavailable. Rockwell-Collin's Reliability Improvement Warranty (RIW), a LCC procurement technique to continuously upgrade reliability of equipment and minimize mean time between failures (MTBF), is well recognized. (11)

In the economic analysis of Federal grants for rolling stock equipment versus subsidy for operations of transit buses, William B. Tye uses the Uniform Annual Equivalent (UAE) which is essentially annualized LCC. (12) Tye presents a theoretical bus replacement model to test the hypothesis that bus transit carriers are undercapitalized. The UAE curves, like LCC curves, are U-shaped and have a minimum. Using data for Chicago and Cleveland transit buses, he draws a family of UAE curves showing average annual miles. The UAE curves are then translated into Uniform Continuous Equivalent (UCE) cost curves that show the cost per vehicle mile as a function of vehicle age in years at replacment and yearly output (Figure 3.3). The resemblance between Tye's UCE curves and the LCC curves prepared for this study is quite noticeable.

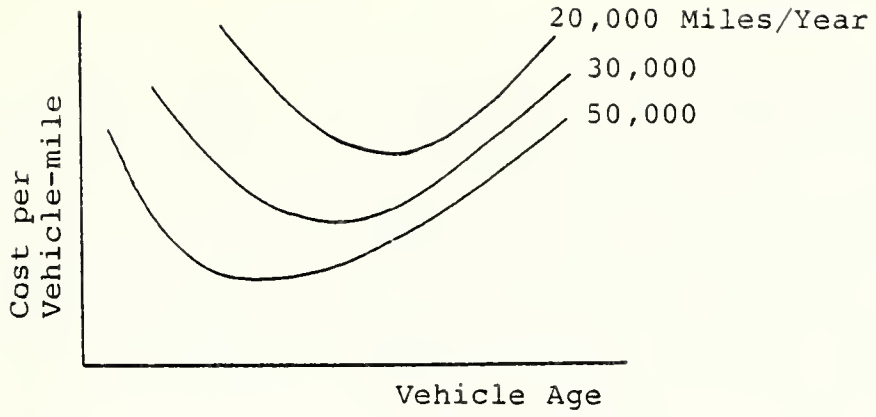


Figure 3.3: Uniform Continuous Equivalent Costs

Source: William E. Tye, pp. 819.

According to Tye, the evidence indicated that for a transit bus the output of 50,000 miles per year should be maintained for 15 years and the 22,000 miles output for 24 years to minimize UAE. The finding that greater output per year reduces per mile cost is also supported by this study. In addition, the larger output gives greater vehicle life in total miles than a smaller number of miles per year. Tye finds that the carriers are not capital poor but need to increase output--the service miles--to optimize, thus making an economic case for government subsidy for transit operations.

Posner's work on life cycle costing provides important groundwork in understanding the role of discount rate in optimum replacment policy.(13) He concludes that the choice of discount rate does not affect optimum policy very much but rather affects only the figure computed for discounted future costs because LCC curves generally have a broad minimum. A large increase in discount rate is usually needed to make a significant change in

optimum replacement level (Figure 3.4). Posner argues that the discount rate should represent the "social discount rate" the value of money for social investment. Thus, he says the rate may be about 2%, but should not be nearly as high as the inflation rate. The present analysis supports Posner's findings and uses a discount rate of 3.2 percent based on the rate of growth in the U.S. gross national product in constant dollars between 1960 and 1975.

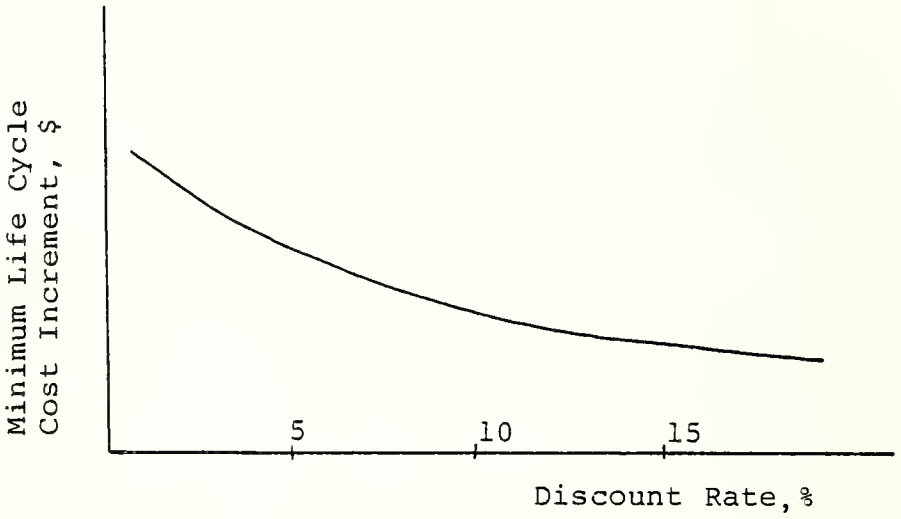


Figure 3.4: Life Cycle Cost Increment and Discount Rate
Source: Posner, 1976

J. Edward Anderson relates life cycle cost analysis to reliability allocation in transit systems. (14) His approach is significant because reliability is used as a constraint rather than cost and the total system reliability is construed as a function of subsystem reliabilities. Standard Lagrangian minimization is used. The subsystem reliability is measured by

mean time between failures (MTBF) and the system unavailability is defined as a ratio of passenger-hours of delay and total passenger-hours travel time. The LCC of a system, according to Anderson, is the sum of the installed costs of all subsystems, plus the sum of the operating and maintenance (support) cost of all subsystems as illustrated in Figure 3.5.

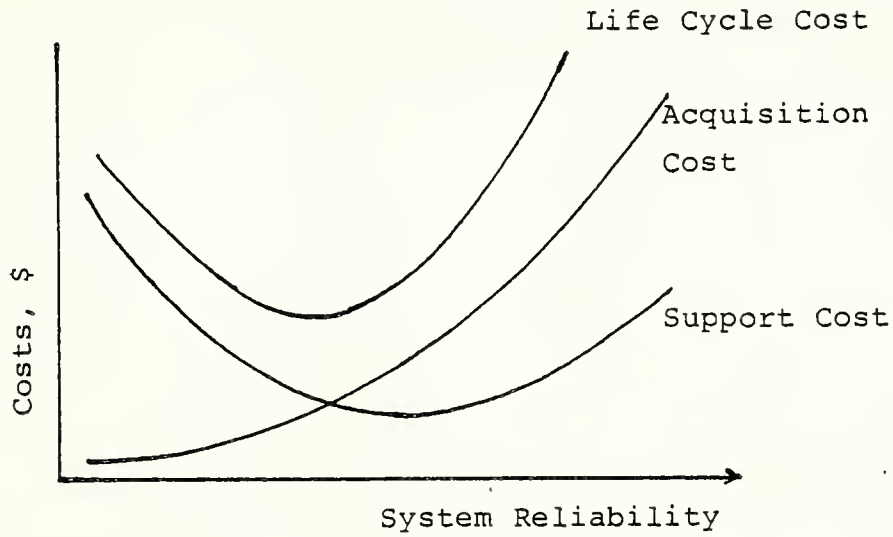


Figure 3.5 Life Cycle Cost as Function of System Reliability

Source: Anderson, 1977.

Anderson's approach in measuring total costs deserves considerable merit in that the system and subsystem reliability are directly considered to determine life cycle cost. The problem of defining reliability and delays, and lack of data on system and subsystem reliability and costs are important obstacles. With improving data based on the RTA's transit operations, however, Anderson's approach deserves to be considered in the future. It should be noted that Anderson's LCC analysis is a single cycle approach since subsequent replacements are not considered. Therefore, his approach cannot be used for optimum replacement analysis.

Introduction of a new generation bus--the transbus--has revived the need to consider life cycle cost of two products, the conventional, present day transit bus that costs $70 - $75,000 compared with the transbus that may cost around $100,000. A report on cost impact of the transbus program by Booz-Allen Applied Research and Simpson and Curtin for UMTA suggests the need for better data on cost of bus operation and maintenance.(15) Although the UMTA report compares total cost of the buses, it a priori assumes the same life span for the competing vehicles. The report concludes that on per mile basis, the new generation transit buses will cost more than the present ones, but fails to determine whether the new buses are justified on economic ground, since LCC based on reliability and optimum replacement is not considered.

In 1977 UMTA awarded a contract to the Metropolitan Suburban Bus Authority (MSBA) to study the concept of life cycle costing in bus procurement.(16) According to the Advanced Management Systems, Inc., the consultant to do the study, the MSBA's sophisticated management information system will provide comprehensive cost data for specific area, such as transmissions, total amount of mileage, fuel consumption, and repair cost of individual buses over 12 years, in other words, a biography of a bus. The MSBA study provides a very persuasive argument to develop subsystem data base for life cycle costing of all transit vehicles.

Another recent UMTA study by Advanced Management Systems, Inc. reports using LCC in the evaluation of current Rohr and AM General buses and General Motors RTS-II buses.(17) Although the study advances the need for LCC for bus procurement, and offers detailed cost per mile for various carriers around the country, the effect of age on support costs, reliability, and variation in life span are not considered. General lack of data on transit rolling stock support cost is seen as an important problem in applying LCC analysis to vehicle management problems.

The Ottawa-Carleton Regional Transit Commission's prodcedure for evaluation of tenders shows a practical application of LCC with minimum data and computations. (18) The procedure adds the cost of initial procurement, excess fleet cost (as substitute for availability cost), road call cost (as substitute for reliability), and support costs as increasing function of age in years of competing bids over a designated number of years of service. Like most studies Ottawa-Carleton's procedure does not consider reprocurement costs.

The need to apply LCC to a variety of products and industries is now well recognized. A joint conference in October 1977 of the American Institute of Industrial Engineers and the American Association of Cost Engineers, "Life Cycle Costing: A New Approach to Systems," in Washington, D.C., underlines the professional and management interest in the subject matter. Increasing support cost of equipment and buildings as well as cost inflation have created new pressures to consider costs other than initial procurement in replacement and acquisition decisions.

What is next in LCC? The answer is universally the long process of developing the data base. In the transit industry, long starved for public funds, information on performance and costs is very scarce. Life history of vehicles is not kept. Further, data must be computer based for automatic retrieval and should accommodate many management and financial reporting functions. A well-designed transit LCC information system will serve for more than intelligent vehicle replacement decisions. It can serve for comparing competing bids, deciding the number of miles a specific vehicle should be used, and the level of maintenance at which desired system and subsystem reliabilities can be achieved at minimum long term cost.

d. Replacement/Rebuilding Decisions Using LCC Analysis:

The following discussion illustrates the comprehensiveness and advantages of LCC with replacement over the single-cycle and cumulative average per mile cost analysis. Figure 3.5 shows two cases involving $10,000 extraordinary expense in the 5th and the 11th year of life of a transit bus that is used at a constant annual rate of 40,000 miles. In both cases, for simplicity, growth rates of all costs are assumed to be zero while the discount rate is 3.2 percent. Further, it is assumed that the extraordinary expense which could be a result of an accident or damage from natural causes, does not affect future maintenance, depreciation, or reliability costs after the required repairs.

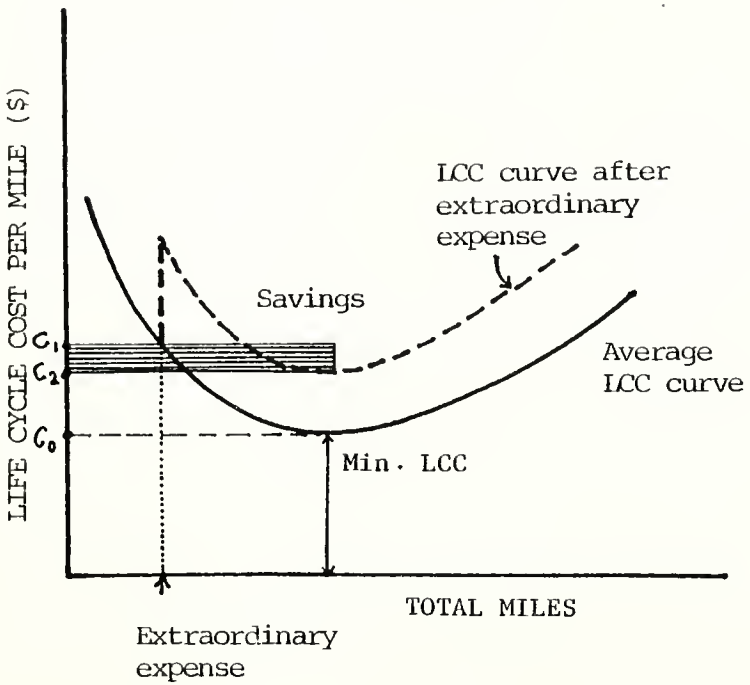
In both instances, the LCC of the bus increases above the normal LCC of similar buses without the extraordinary expense. In the first case, at the 5th year the normal LCC is C_1. After repairs, the lowest LCC achievable is C_2 which is less than C_1. This leads to a conclusion to repair. In the second case, however, C_2*, the lowest possible LCC after repairs, is greater than the prerepair level of C_1*. It is, therefore, not economical to repair the bus and must be replaced. Table 3.1 uses hypothetical LCC figures to demonstrate the replacement/rebuilding decision process. It shows that the management may be willing to spend a sum of $10,000 on a relatively newer bus but not on an older one. In case I, the numbers suggest that the repaired vehicle must be used at least until the LCC falls below the prerepair level of $17.67, or the 7th year, to justify repairs.

Although the illustrated example is too simple, the complex real world costs can be added and the benefits, if any, be subtracted to make optimum decisions. Naturally, the analysis is most applicable in developing general rules and guidelines for major repairs and rebuilding since each vehicle and rebuilding situation is unique in terms of costs, benefits, and vehicle condition. The life cycle cost analysis forces management to ask and answer relevant questions and justify replacement/rebuilding decisions on financial and economic ground. Improvements in the above decision process can be made with better data on risks and probabilities of repairs and a number of other economic and non-economic issues not considered here.

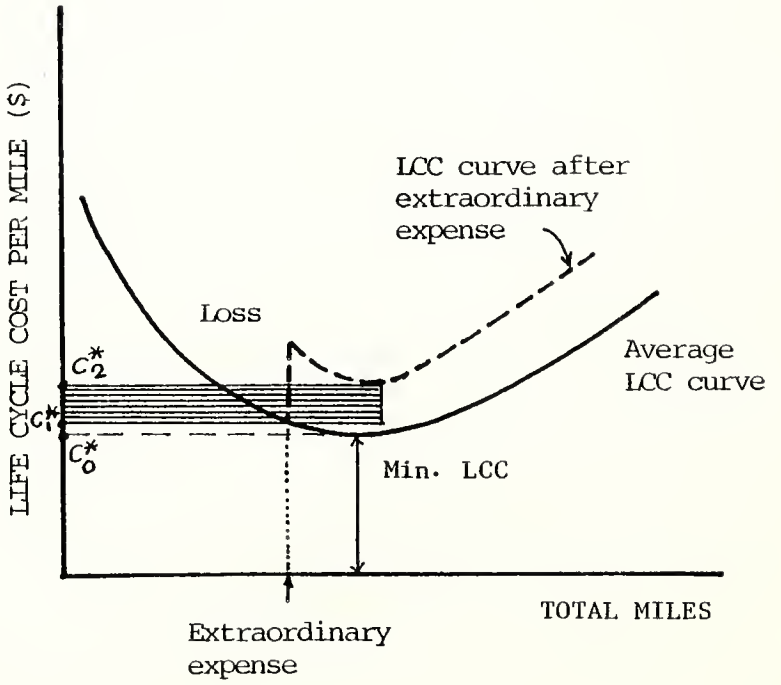
FIGURE 3-6

BASIC CONCEPTS OF DECISION MAKING ON EXTRAORDINARY EXPENSE ON TRANSIT BUSES

Using Life Cycle Cost Analysis Approach



CASE I: The minimum LCC after extraordinary expense is less than just before the repair. Conclusion: The bus should be repaired.



CASE II: The minimum LCC after extraordinary expense is greater than just before the repair. Conclusion: Replace the bus.

TABLE 3-1

DECISION MAKING ON EXTRAORDINARY MAINTENANCE VS. REPLACEMENT OF TRANSIT BUSES

Using Life Cycle Cost Analysis Approach

Hypothetical Average Life Cycle Costs

Vehicle Age in Years	Vehicle Life Miles	Average LCC, $	LCC Per Mile, Per Year, $	Case I: Extra-ordinary Expense, $	Case I: Addition to LCC, $	Case I: New Per Mile LCC, $	Case II: Extra-ordinary Expense, $	Case II: Addition to LCC, $	Case II: New Per Mile LCC, $
1	40,000	1,025,490	25.6373						
2	80,000	919,810	22.9952						
3	120,000	837,233	20.9308						
4	160,000	761,378	19.0345			17.6686			
5	200,000	706,743	17.6686	10,000	57,378	19.1030			
6	240,000	664,207	16.6051		48,777	17.8245			
7	280,000	641,207	16.0302		42,460	17.0917			
8	320,000	614,288	15.3572		37,727	16.3004			
9	360,000	592,107	14.8027		34,051	15.6540			
10	400,000	576,033	14.4008		31,115	15.1787			
11	440,000	565,661	14.1415		28,717	14.8594	10,000	23,702	14.7341
12	480,000	560,388	14.0097		26,723	14.6778		22,056	14.5611
13	520,000	558,862	13.9716		25,038	14.5975		20,666	14.4882
14	560,000	557,349	13.9337*		23,598	14.5237		19,477	14.4206
15	600,000	558,348	13.9587		22,352	14.5175*		18,449	14.4199*
16	640,000	560,056	14.0014		21,265	14.5330		17,551	14.4402
17	680,000	564,408	14.1102		20,308	14.6179		16,762	14.5292
18	720,000	569,889	14.2472		19,461	14.7337		16,062	14.6487
19	760,000	576,292	14.4073		18,704	14.8749		15,438	14.7932
20	800,000	583,451	14.5863		18,026	15.0369		14,878	14.9582

NOTE: At discount rate of 3.2 percent per year, the present value of $10,000 in 5 years is $8,521 and $7,033 in 11 years.

* Minimum life cycle cost per mile per year.

Decision on Case I - Extraordinary maintenance is justified.

Case II - Extraordinary maintenance is not justified. Replace the bus after 400,000 miles.

4. REPLACEMENT ANALYSIS OF RTA BUSES

The objective of this chapter is to present the process and the results of application of life cycle cost analysis explained in the preceding chapter to the buses of the suburban carriers of the Regional Transportation Authority (RTA). First, the efforts to collect and construct relevant data on maintenance, depreciation, reliability and special depreciation costs are explained. Next, the results of the life cycle cost analysis and optimum replacement age of buses by total vehicle miles and age in years are examined taking into account the effect of discount rates, net growth in various costs, initial purchase price and output level-the annual miles per year. Limitations and capabilities of the present analysis for actual replacement/ rebuilding decisions are noted.

a. Transit Bus Costs:

The three basic cost components of transit rolling stock for LCC analysis are maintenance, depreciation, and reliability. Fuel cost, if conceived as a function of vehicle age, should also be included. Since time value of money is significant in life cycle costing, all costs must be reported in present value and be related to annual use of vehicle. The bus maintenance and reliability cost estimates for the present study depend largely on the Vehicle Maintenance and Operation Reporting System (VMORS) of the RTA covering some 500 buses of the suburban carriers.(17) VMORS includes monthly miles, fuel consumption, and repair and road call costs for most of the buses. Since this information system became operational only in June, 1977, only six month cost

data were available at the time of the present study in January, 1978. A complete set of data covered 288 buses that form the basis for cost estimates. The quality of the data are believed to be excellent. With a few exceptions, there were sufficient number of buses in each age category. No bus in the sample had over 500,000 miles.

i. Maintenance Cost:

For the purpose of the present bus study, maintenance cost includes all repairs, major overhauls and fuel. The routine maintenance and inspections, and overheads, such as washing, cleaning, changing bulbs, real estate and construction costs of garages, as well as driver salaries are not included. All 288 buses in the sample were identified by total life miles. If total miles were not available, especially on older buses or where hubodometers were changed, they were estimated on the basis of model year and the average annual miles by the carrier. Newer buses were assumed to average more miles per year than the older ones. Buses were not classified by accessaries such as air-conditioning, type of service-urban vs. rural-or size. Admittedly, these ommissions distort the cost picture, especially for repairs and fuel. Table 4.1 lists the per mile maintenance cost of 288 buses by total miles and carriers. The relative effect of ommissions and distortions was small because a smoothed repair cost curve was developed from the base

PER MILE REPAIR AND MAINTENANCE COST OF SELECTED
RTA BUSES AND CARRIERS BY BUS LIFE MILES

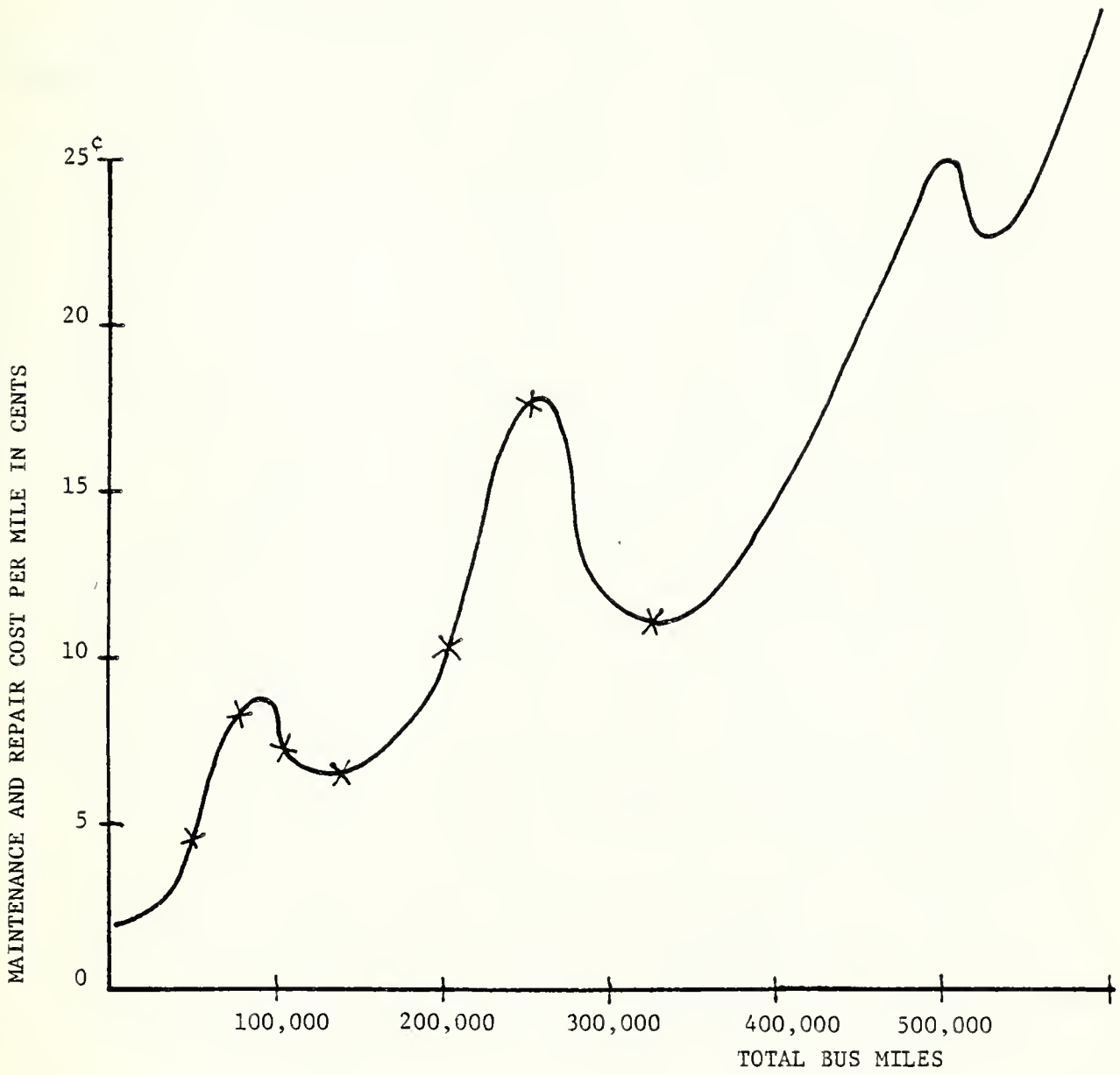
CARRIERS

Bus Life Miles Interval	Aurora*	Elgin*	Joliet	NORTRAN	Safeway	Sub. Tran.	WNCTC	Total
30,000-59,999								
No. of Buses	11	8	6	25	6	8	5	69
Cost/Mile,¢	6.0	7.6	4.7	3.8	3.5	4.1	5.6	4.8
60,000-89,999								
No. of Buses	-	2	1	68	7	17	2	97
Cost/Mile, ¢	-	2.8	2.3	9.7	3.6	7.0	4.4	8.5
90,000-119,999								
No. of Buses	11	-	14	-	-	2	-	27
Cost/Mile,¢	15.0	-	3.8	-	-	8.9	-	7.2
120,000-149,999								
No. of Buses	-	4	5	-	-	-	-	9
Cost/Mile, ¢	-	7.2	6.5	-	-	-	-	6.8
180,000-209,999								
No. of Buses	-	-	-	-	54	-	3	57
Cost/Mile, ¢	-	-	-	-	9.0	-	10.8	9.1
240,000-269,999								
No. of Buses	-	-	-	-	-	-	3	3
Cost/Mile, ¢	-	-	-	-	-	-	17.8	17.8
300,000-349,999								
No. of Buses	-	-	-	-	18	-	3	21
Cost/Mile, ¢	-	-	-	-	10.1	-	15.7	10.9
400,000-449,999								
No. of Buses	-	-	3	-	-	-	-	3
Cost/Mile, ¢	-	-	6.4	-	-	-	-	6.4
450,000-499,999								
No. of Buses	-	2	-	-	-	-	-	2
Cost/Mile, ¢	-	12.4	-	-	-	-	-	12.4
All Buses								
No. of Buses	22	16	29	93	85	27	16	288
Cost/Mile, ¢	10.5	7.5	4.7	8.1	8.4	6.3	10.6	7.9

Source: A six-month survey of repair and maintenance of selected RTA suburban carriers, July thru December, 1977. West Town does not report maintenance. Only buses with complete cost and mileage records are included.

* Non-union shops.

FIGURE 4-1: MAINTENANCE AND REPAIR COST PER MILE AND TOTAL TRANSIT BUS MILES

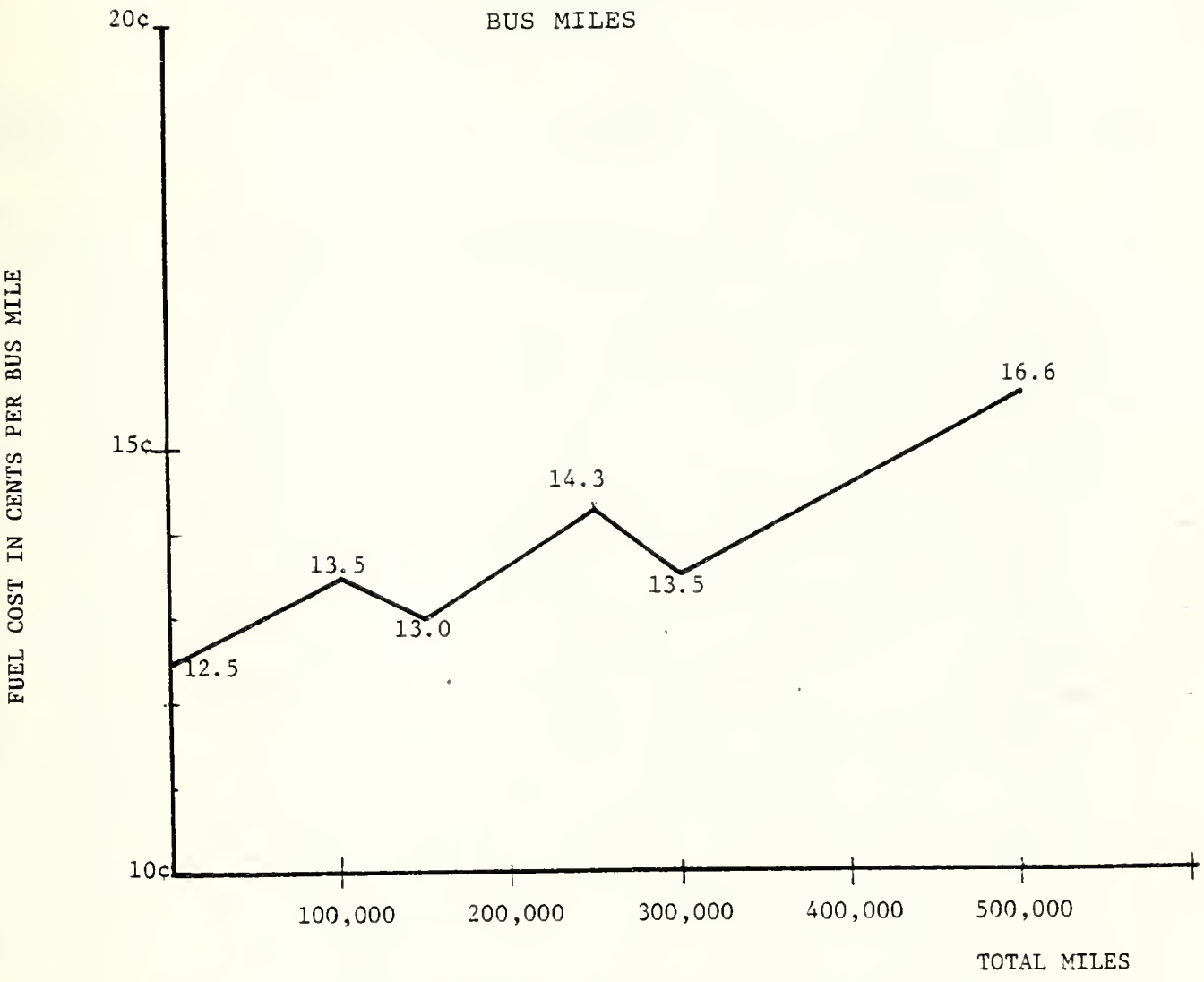


SOURCE: The asterisks are points of average cost observed on RTA suburban bus carriers based on vehicle maintenance data of some 300 buses with complete mileage and maintenance cost data from July thru December 1977. The curve is hand-fitted and reflects the maintenance practices of the transit industry for overhaul and heavy repairs.

data (figure 4.1). The fluctuations in per mile maintenance data can be readily explained by the nature of incidence of vehicle failures and the industry practices. According to the RTA maintenance personnel, heavy repairs and overhauls on transit buses are generally performed at 100,000, 250,000 and 500,000 life miles. Engines are normally replaced at 500,000 miles. Cyclical cost patters are also found in locomotive repairs and are commonly experienced in other equipment maintenance environs.

Fuel consumption cost is based on a price of 50 cents per gallon of diesel. The CTA experience was the basis for determining the per mile fuel cost of buses (20). Although no clear picture on the effect of age on fuel efficiency emerges from the CTA data because of aggregation by bus series, they do indicate some range. Because new buses are air-conditioned, they give fewer miles per gallon than the older ones. The per mile fuel cost for the new CTA buses was 9.25 cents compared with 10.25 cents for the 2 and 3 years old, similarly equipped, buses. Figure 4.2 relates to the per mile estimated fuel cost to the age of transit bus in miles. The fluctuating cost curve attempts to reflect the benefits of major maintenance expenditures of fuel efficiency. Basically, it is assumed that

FIGURE 4.2: FUEL COST PER MILE AND TOTAL TRANSIT BUS MILES



Note: 4 mpg. at 50¢ / gallon = 12.5¢ / mile
3.5 mpg. at 50¢ / gallon = 14.28¢ / mile
3.0 mpg. at 50¢ / gallon = 16.66¢ / mile
2.5 mpg. at 50¢ / gallon = 20.00¢ / mile

SOURCE: This Figure is based on general concept of declining gas mileage because of age of vehicle alone. The declines in cost reflect general overhauls and repairs as practiced by the industry, and correspond with maintenance cost curve used in this study. See Figure .

the new vehicles would give 4 miles per gallon, or 12.5 cents per mile. After 500,000 miles the fuel efficiency declines to 3.0 mpg, or 16.6 cents per mile, a decline in efficiency of nearly 33 percent.

ii Reliability Cost:

Reliability cost, for the purpose of the present study, is the sum of the cost of the reserve fleet requirement and the expense of road calls. In the six month study period, the 288 RTA buses reported 882 road calls (Table 4.2). For each age category by life miles, the number of road calls per 10,000 miles of service was determined. The result shows a weak pattern of increase in road calls with age for some carriers. It is possible that some carriers delayed required maintenance longer than the others. Based on this rather weak evidence a road calls chart was constructed showing the number of expected road calls per 10,000 miles (Figure 4.3). Each road call was assigned an average cost of $30, a figure found to be representative of RTA's experience in 1977.

The reserve fleet requirement cost was determined on the basis of general transit industry opinion of 10 percent reserve vehicles. A charge of 10 percent of annual maintenance and fuel cost was made to the reliability cost to reflect cost of maintaining a reserve fleet.

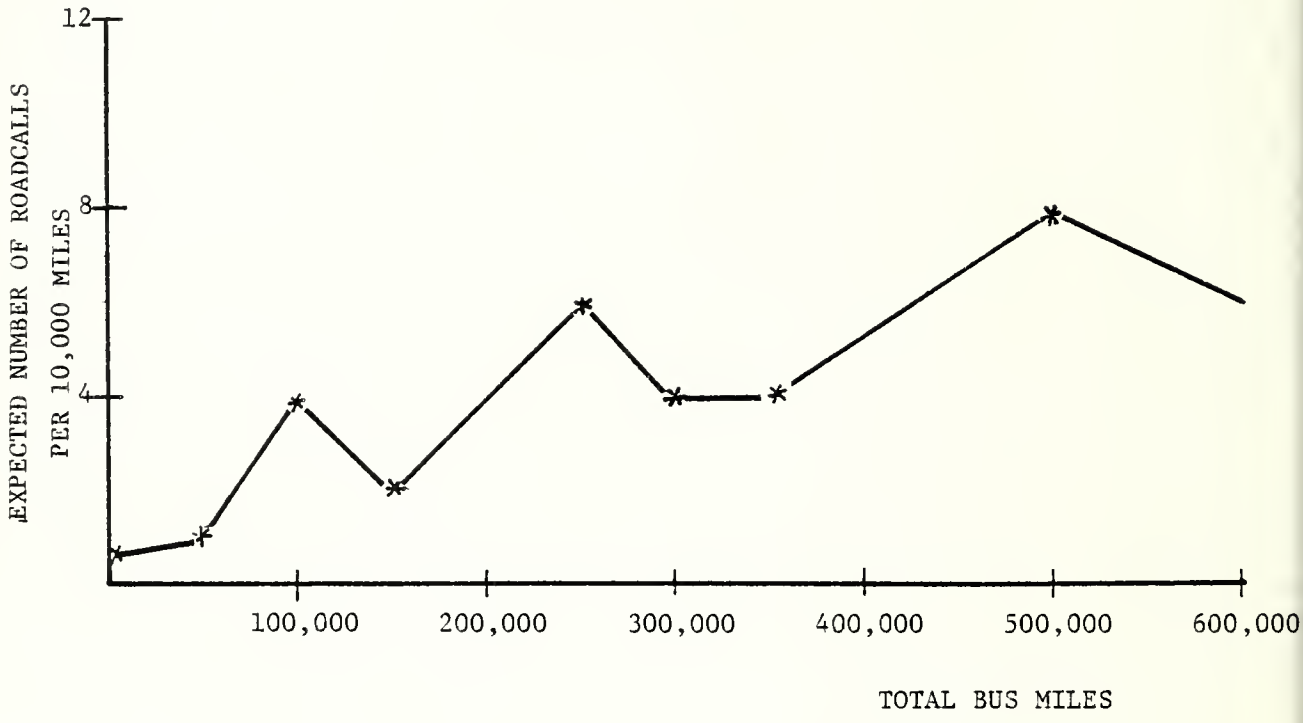
TABLE 4-2

ROAD CALL RATES OF SELECTED RTA BUSES AND CARRIERS BY BUS LIFE MILES
July thru December, 1977

is Life iles Interval	CARRIERS Aurora	Elgin	Joliet	NORTRAN	Safeway	Sub. Tran.	WNCTC	Total
),000-59,999								
No. of Calls	88	29	34	53	4	13	25	246
Calls/10,000M.	7.03	1.71	4.7	1.06	0.37	0.80	1.97	
),000-89,999								
No. of Calls	-	0	4	225	7	50	11	297
Calls/10,000M.	-		1.45	2.16	0.38	1.4	1.56	
),000-119,999								
No. of Calls	66	-	121	-	-	3	-	190
Calls/10,000M.	3.25	-	4.10	-	-	0.78	-	
20,000-149,999								
No. of Calls	-	-	33	-	-	-	-	33
Calls/10,000M.	-	-	4.00	-	-	-	-	
30,000-209,999								
No. of Calls	-	-	-	-	58	-	8	66
Calls/10,000M.	-	-	-	-	0.52	-	1.97	
40,000-269,999								
No. of Calls	-	-	-	-	-	-	5	5
Calls/10,000M.	-	-	-	-	-	-	1.92	
00,000-349,999								
No. of Calls	-	-	-	-	19	-	4	23
Calls/10,000M.	-	-	-	-	0.94	-	2.4	
00,000-449,999								
No. of Calls			19					19
Calls/10,000M.			6.48					
50,000-499,999								
No. of Calls		3						3
Calls/10,000M.		4.87						
Total								
No. of Calls	154	32	211	278	88	66	53	882

ource: A six-month survey of repair and maintenance of selected RTA uburban carriers, July thru December, 1977. West Town does not report aintenance. Only buses with complete cost and mileage records are ncluded.

FIGURE 4.3:EXPECTED RATE OF ROAD CALLS AND TRANSIT BUS MILES



SOURCE: The asterisks are points observed in the actual road call data for some 300 RTA suburban buses from July thru December 1977. The curve is hand-fitted and corresponds to maintenance cost data used for this study.

Excluded from the reliability cost is the delay cost which could not be determined from present data. The cost of riders' wasted time and loss of business to the authority may be very insignificant for a highly reliable system but quite high for an extremely old fleet. The reliability cost in the present analysis, therefore, is believed to be understated. The LCC analysis procedure presented in this paper is not designed to consider reliability as a critical variable.

iii Depreciation Cost

As defined earlier in Section 3-b, the depreciation cost of a transit bus in any year (t) is the difference in market values in the preceding year (t-1) and the year (t). Since transit buses do not have a real competitive resale market for trade-in, like automobiles, there is no real life experience on market value of buses of various ages. If the total acquisition cost is assigned to the year of replacement, the costs will be overstated in the early years of vehicle and understated later. A theoretical depreciation cost curve was developed that is convex and assigns about 22 percent of acquisition cost to the first 25,000 miles. Depreciation cost diminishes to almost zero when the vehicle reaches 500,000 miles.

The depreciation cost function is given by

$$D(t) = MP_{t-1} - MP_t$$

where

MP_t = $MP_0 \cdot (1-\exp(-1(t/100000)))$

MP_0 = Market price at t=0, that is, purchase price in 1977

and t = Total vehicle life miles.

iv. Special Appreciation

Since major overhauls and repairs may enhance the market value of vehicles, a part of the major maintenance cost should be depreciated over the following periods if they continue to be in use, or their trade-in-value should be increased. Since the maintenance curve used for the present analysis reflects the improved efficiency of the overhauled vehicles, no appreciation value is assigned.

v. Annual and Cumulative Average Per Mile Costs:

The total cost of operating and maintaining and replacing the transit bus is the sum of depreciation, maintenance and fuel, and reliability costs defined earlier. To allow for variation in annual miles per transit bus, total costs were determined for every 10,000 miles interval to 800,000 miles. Four output policies were considered. The three constant miles policies assumed annual usage of 25,000, 30,000 and 40,000 miles. The fourth policy allowed as many as 50,000 miles in

TABLE 4-3

ANNUAL MILES, MAINTENANCE, DEPRECIATION, RELIABILITY AND TOTAL COST

TABLE 4-3A FOR SUBURBAN TRANSIT BUSES

YEAR	MILES	MAINT.$	DEPR.$	REL.$	COST/YR.	AVE.COST
1	25000.	3662.	16590.	95.	20347.	0.8139
2	25000.	4055.	12920.	146.	17121.	0.7494
3	25000.	5050.	10062.	302.	15414.	0.7051
4	25000.	5525.	7837.	458.	13819.	0.6670
5	25000.	5140.	6103.	441.	11684.	0.6271
6	25000.	4945.	4753.	352.	10050.	0.5896
7	25000.	5115.	3702.	371.	9188.	0.5578
8	25000.	5737.	2883.	500.	9119.	0.5337
9	25000.	6020.	2245.	594.	8859.	0.5138
10	25000.	6277.	1749.	690.	8715.	0.4973
11	25000.	7718.	1362.	834.	9914.	0.4881
12	25000.	6633.	1061.	658.	8351.	0.4753
13	25000.	6275.	826.	585.	7686.	0.4624
14	25000.	6280.	643.	578.	7501.	0.4508
15	25000.	6590.	501.	612.	7702.	0.4413
16	25000.	7175.	390.	718.	8283.	0.4344
17	25000.	7713.	304.	801.	8818.	0.4296
18	25000.	8450.	237.	925.	9612.	0.4271
19	25000.	9200.	184.	1043.	10427.	0.4265
20	25000.	9950.	144.	1125.	11219.	0.4277
SUM =	500000.	127510.	74495.	11824.	213828.	

TABLE 4-3B

YEAR	MILES	MAINT.$	DEPR.$	REL.$	COST/YR.	AVE.COST
1	30000.	4430.	19439.	119.	23988.	0.7996
2	30000.	5100.	14400.	243.	19743.	0.7289
3	30000.	6470.	10668.	478.	17616.	0.6816
4	30000.	6335.	7903.	574.	14812.	0.6347
5	30000.	5620.	5855.	423.	11897.	0.5870
6	30000.	6750.	4337.	540.	11627.	0.5538
7	30000.	6225.	3213.	558.	9996.	0.5223
8	30000.	6737.	2380.	709.	9826.	0.4979
9	30000.	9450.	1763.	1037.	12250.	0.4880
10	30000.	8031.	1306.	791.	10128.	0.4729
11	30000.	7425.	968.	690.	9083.	0.4575
12	30000.	7770.	717.	707.	9194.	0.4449
13	30000.	8230.	531.	810.	9571.	0.4352
14	30000.	9207.	394.	958.	10558.	0.4293
15	30000.	9891.	292.	1079.	11262.	0.4257
16	30000.	11075.	216.	1258.	12548.	0.4252
17	30000.	12494.	160.	1451.	14105.	0.4279
18	30000.	12150.	119.	1350.	13619.	0.4293
19	30000.	12600.	88.	1320.	14008.	0.4313
20	30000.	14011.	65.	1401.	15477.	0.4355
SUM =	600000.	170001.	74814.	16493.	261308.	

(Continued)

ANNUAL MILES, MAINTENANCE, DEPRECIATION, RELIABILITY AND TOTAL COST

TABLE 4-3C

YEAR	MILES	MAINT.$	DEPR.$	REL.$	COST/YR.	AVE.COST
1	40000.	6025.	24726.	163.	30913.	0.7728
2	40000.	7865.	16574.	413.	24852.	0.6971
3	40000.	8610.	11110.	801.	20521.	0.6357
4	40000.	7935.	7447.	568.	15950.	0.5765
5	40000.	8915.	4992.	732.	14639.	0.5344
6	40000.	9167.	3346.	935.	13448.	0.5013
7	40000.	12326.	2243.	1357.	15926.	0.4866
8	40000.	10220.	1504.	950.	12674.	0.4654
9	40000.	10270.	1008.	927.	12205.	0.4476
10	40000.	11200.	676.	1130.	13006.	0.4353
11	40000.	12678.	453.	1354.	14485.	0.4287
12	40000.	14575.	304.	1628.	16506.	0.4273
13	40000.	16350.	204.	1935.	18489.	0.4300
14	40000.	16175.	136.	1803.	18114.	0.4317
15	40000.	17850.	91.	1835.	19776.	0.4358
16	40000.	19200.	61.	2000.	21261.	0.4418
17	40000.	20400.	41.	2200.	22641.	0.4491
18	40000.	21600.	28.	2400.	24028.	0.4575
19	40000.	22800.	18.	2600.	25418.	0.4669
20	40000.	24000.	12.	2800.	26812.	0.4771
SUM =	800000.	278161.	74975.	28527.	381663.	

TABLE 4-3D

YEAR	MILES	MAINT.$	DEPR.$	REL.$	COST/YR.	AVE.COST
1	50000.	7730.	29510.	248.	37488.	0.7498
2	40000.	8370.	14997.	605.	23972.	0.6829
3	40000.	8330.	10053.	719.	19102.	0.6197
4	40000.	7970.	6739.	517.	15226.	0.5635
5	40000.	9345.	4517.	883.	14744.	0.5263
6	30000.	6712.	2380.	709.	9801.	0.5014
7	30000.	9420.	1763.	972.	12155.	0.4907
8	30000.	8006.	1306.	791.	10103.	0.4753
9	25000.	6275.	826.	585.	7686.	0.4624
10	25000.	6280.	643.	578.	7501.	0.4508
11	20000.	5230.	411.	474.	6115.	0.4430
12	20000.	5600.	336.	565.	6501.	0.4369
13	20000.	5920.	275.	592.	6787.	0.4321
14	20000.	6338.	225.	667.	7230.	0.4289
15	20000.	6860.	185.	750.	7795.	0.4271
16	10000.	3000.	79.	400.	4079.	0.4267
17	10000.	3715.	72.	420.	4207.	0.4266
18	10000.	3805.	65.	433.	4302.	0.4267
19	10000.	3945.	59.	455.	4459.	0.4270
20	10000.	4110.	53.	485.	4648.	0.4278
SUM =	500000.	127561.	74495.	11846.	213901.	

in the first year of service but only 10,000 miles per year in the 16th through 20th years, accumulating a total of 500,000 miles, or an average of 25,000 miles per year. The latter, called the decreasing miles policy, represents a practice by many carriers. It is of interest to examine this practice against the constant miles usage from economic considerations.

Tables 4.3 A, B, C, and D present the annual cost of maintenance (including fuel), depreciation and reliability for the four output alternatives. No more than 20 years of life is considered from an a priori determination that a 20 year old vehicles will be an obvious candidate for replacement, irrespective of the mileage. The last columns give the annual per mile average cost. For all outputs, the minimum per mile average cost is at 475,000 miles and the minimum cost is the same, about 42.66 cents per mile, regardless of the number of annual miles, or the bus life in years. The absence of time value of money is quite apparent. Further, replacement costs are not considered, or assumed to be constant over time.

vi. Average Cost Under Increasing Prices:

If the vehicle costs increase over time, the minimum average cost moves to a lower level of total vehicle use as present value of future costs increase exponentially. Table 4.4 shows the minimum average cost for the four alternative output levels and price increases from zero to ten percent annually.

TABLE 4-4

MINIMUM AVERAGE PER MILE COST FOR TRANSIT BUS UNDER INCREASING REAL COSTS

BY LIFE MILES AND YEARS

Annual Rate of Increase in Costs, %		25,000 miles/year	30,000 miles/year	40,0000 miles/year	Decreasing Miles
0.0	Cost,¢	42.65 ¢	42.52 ¢	42.73 ¢	42.66 ¢
	Miles	475,000	480,000	480,000	470,000
	Years	19	16	12	17
1.5	Cost,¢	48.24	47.23	46.28	46.43
	Miles	425,000	450,000	440,000	430,000
	Years	17	15	11	14
3.2	Cost,¢	55.09	53.79	50.57	50.74
	Miles	375,000	390,000	400,000	390,000
	Years	15	13	10	12
5.0	Cost,¢	62.84	59.12	55.36	55.32
	Miles	350,000	360,000	360,000	370,000
	Years	14	12	9	11
10.0	Cost,¢	79.60	73.86	67.53	65.95
	Miles	240,000	240,000	240,000	240,000
	Years	7	8	6	6

Refer to Tables 4-3- A,B,C,D for the base data with zero inflation level. See Appendix II for annual cost by rates of cost increase.

At zero rate eachoutput level has the same minimum average cost of around 42.65 cents at 475,000 miles. If costs increase at a rate of ten percent, the minimum average goes up for all output levels but more so for the low output levels than the high ones. The minimum average per mile cost for a 30,000 miles a year bus at ten percent rate is 73.86 cents compared with 67.52 cents for the one used 40,000 miles. Since replacement costs are not considered, the output rates have no effect on the minimum average cost total miles. The inflation, however, reduces the minimum average cost total miles to 240,000 at ten percent growth in costs.

b. Optimum Bus Replacement:

This section examines the life cycle cost increment - the future costs of operating, maintaining and replacing a transit bus over an infinite, or a very long time period - by various scenarios of annual vehicle miles, discount rates, and net growth rates in costs of maintenance, depreciation, and reliability described in the preceding section. Table 4.5 summarizes the total miles and number of years a transit bus with specified cost functions should be used to minimize life cycle cost increment per mile. The four annual output miles alternatives are considered with four real cost increase scenarios for an initial, current acquisition cost of $75,000. The effect of sudden price increase on optimum replacement to $100,000 is examined for the two scenarios; no price rise and increase equal to the discount rate of 3.2 percent.

i. Cost Increase Equal to Discount Rate:

When costs in constant dollars rise at the same rate as the discount rate, the net effect is to cancel out the time effect of money. The optimum replacement age can be simply determined by minium per mile average cost. Table 4.5 shows that the minimum cost of 42.65 cents per mile is at 475,000 total miles, regardless of the number of annual miles, constant or decreasing. The transit bus under this scenario should be replaced at 475,000 miles to minimize the average per mile cost as well as the LCC increment.

If the initial purchase price of the transit bus increases to say, $100,000, while other costs remain constant, the net effect is to increase depreciation costs relatively. Since depreciation costs are higher in the initial years of use than the later, the increase in price requires longer replacement period to minimize the per mile LCC increment and the average cost. For a bus used 25,000 miles a year, or at decreasing rate, the optimum replacement age increases to over 500,000 miles and more than 20 years. The bus placing 30,000 miles a year at a constant rate, the life span extends to 19 years, or 570,000 miles. Similarly, the 40,000 miles a year system must extend vehicle usage to 560,000 miles, or 14 years. The annual bus miles in this situation has no effect on either the size of the minimum per mile cost, or optimum replacement life miles.

TABLE 4-5

OPTIMUM REPLACEMENT MILES AND YEARS FOR TRANSIT BUS BY LEVEL OF USE, RATES OF COST INCREASE AND INITIAL PURCHASE PRICE

Annual Rate of Change of Costs, %	Annual Miles per Transit Bus 25,000 Life Miles	Years	30,000 Life Miles	Years	40,000 Life Miles	Years	Decreasing Life Miles	Years
Initial Price $75,000								
8.0%	500,000 +	20 +	540,000	18	480,000	12	500,000 +	20 +
5.0	500,000 +	20 +	540,000	18	480,000	12	500,000 +	20 +
3.2	475,000	19	480,000	16	480,000	12	470,000	17
0.0	475,000	19	480,000	16	480,000	12	450,000	15
- 6.8	535,000*	22	540,000*	18	560,000	14	350,000	10
Initial Price $100,000								
3.2	500,000 +	20 +	570,000	19	560,000	14	500,000 +	20 +
0.0	500,000 +	20 +	570,000	19	560,000	14	450,000	15

*Estimated from Figure 4-4.

ii. Discount Rate of 3.2 Percent or More:

A positive discount rate greater than the cost increase implies that the time value of money is positive in present dollars and postponement of replacment results in benefits or savings. Under these conditions, the future cost is always less in present value. Because of the specific cost functions assumed for a transit bus and since the minimum LCC increment curves have a broad bottom against discount rates, no noticeable change in replacement strategy is indicated by the 3.2 percent net discou rate for the three fixed mileage alternatives. For the declining use alternative, a reduction in life miles to 450,000, or 15 years is indicated from the no cost increase, zero discount rate scenario.

Although 10 percent discount rate over a long time period is not realistic, it is examined here to understand the effect of discounting on replacement decisions. For the fixed miles alternatives, the high rate of discounting results in more life miles for optimum replacment since future higher costs are made more tolerable by the deep discounting. The decreasing miles alternative, with too small advantage of discounting in later years when output is declining, finds it more economical to contract the replacement cycle to 350,000 miles, or 10 years.

Figure 4.4 and Table 4.6 show the LCC increments for 20 annual replacement intervals for the four output alternatives for positive discount rate of 10 percent a year.

TABLE 4-6

LIFE CYCLE COST INCREMENTS FOR TRANSIT BUS BY USE LEVEL
LIFE MILES AND AGE IN YEARS
(Net Discount Rate of 10 % Annually)

	25,000 Miles/Yr.		30,000 Miles/Yr.		40,000 Miles/Yr.		Declining Miles/Yr.		
YR.	LIFE MILES	PER MILE LCC INC.	LIFE MILES	PER MILE LCC INC.	LIFE MILES	PER MILE LCC INC.	LIFE MILES	PER MILE LCC INC.	AVE. YR. MILES
1	25000.	7.738552	30000.	7.602684	40000.	7.348336	50000.	7.128853	50000.
2	50000.	7.155701	60000.	6.963715	80000.	6.663884	90000.	6.504397	45000.
3	75000.	6.706961	90000.	6.548700	120000.	6.127031	130000.	6.027615	43333.
4	100000.	6.443822	120000.	6.152192	160000.	5.627578	170000.	5.550004	42500.
5	125000.	6.119578	150000.	5.766112	200000.	5.279366	210000.	5.255227	42000.
6	150000.	5.825683	180000.	5.499914	240000.	5.012938	240000.	5.110137	40000.
7	175000.	5.583852	210000.	5.256015	280000.	4.885633	270000.	5.050505	38571.
8	200000.	5.402308	240000.	5.074056	320000.	4.724897	300000.	4.973241	37500.
9	225000.	5.255833	270000.	4.988215	360000.	4.593493	325000.	4.943031	36111.
10	250000.	5.137026	300000.	4.879374	400000.	4.501564	350000.	4.912535*	35000.
11	275000.	5.065312	330000.	4.774387	440000.	4.446020	370000.	4.934147	33636.
12	300000.	4.979683	360000.	4.690054	480000.	4.422338	390000.	4.961403	32500.
13	325000.	4.893656	390000.	4.624787	520000.	4.421258	410000.	4.991846	31538.
14	350000.	4.828238	420000.	4.530776	560000.	4.417281*	430000.	5.026396	30714.
15	375000.	4.770887	450000.	4.550225	600000.	4.425853	450000.	5.065248	30000.
16	400000.	4.727765	480000.	4.534976	640000.	4.442559	460000.	5.180748	28750.
17	425000.	4.695461	510000.	4.533462	680000.	4.464644	470000.	5.294788	27647.
18	450000.	4.673896	540000.	4.528941	720000.	4.490612	480000.	5.407076	26667.
19	475000.	4.660708	570000.	4.527292*	760000.	4.519439	490000.	5.517978	25789.
20	500000.	4.654221*	600000.	4.533513	800000.	4.549830	500000.	5.627626	25000.

* Minimum life cycle cost increments.

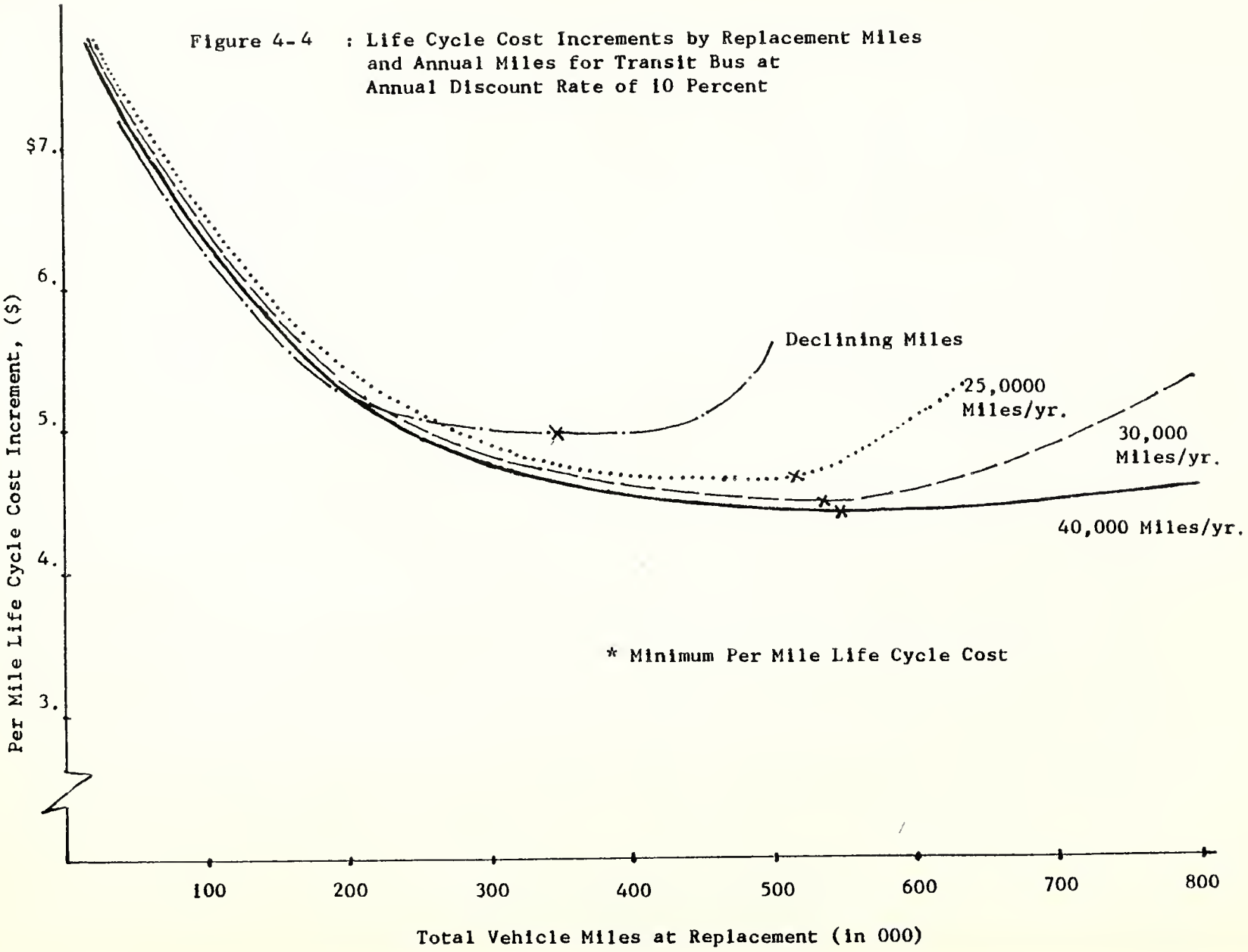


Figure 4-4 : Life Cycle Cost Increments by Replacement Miles and Annual Miles for Transit Bus at Annual Discount Rate of 10 Percent
$7.
6.
5.
4.
3.
Per Mile Life Cycle Cost Increment, ($)
Declining Miles
25,0000 Miles/yr.
30,000 Miles/yr.
40,000 Miles/yr.
* Minimum Per Mile Life Cycle Cost
100
200
300
400
500
600
700
800
Total Vehicle Miles at Replacement (in 000)

It is readily noticed that the high mileage per year results in lower annual cost per mile. The findings substantiate Tye's contention that the transit buses are underutilized, making a case for increased output through greater operating subsidy. (21) A comparison of the decreasing miles policy with the fixed ones suggests that for positive discount rates the declining use policy results in premature replacment and higher per mile life cycle cost.

iii Cost Increase of 5.0 Percent:

If maintenance, fuel, reliability, and acquisition costs increase at a rate of 5 percent a year in constant dollars, while the future values are discounted at 3.2 percent, the costs increase at the differential rate of 1.8 percent - a negative discount rate. The effect of increasing costs is to extend the optimum replacment period to minimize LCC increment. Table 4.7 presents the LCC increments for the four mileage alternatives by life miles for one to 20 years replacment intervals.

This increasing cost scenario requires that a bus placing 25,000 miles, or decreasing miles be replaced after 20 years, or more than 500,000 miles. (22) The 30,000 miles a year transit bus minimizes LCC increment at 540,000 miles or 18 years compared with 480,000 miles if there were no cost increase. The optimum replacment schedule for a bus used 40,000 miles a year is unaffected by the 5 percent increase, or that the change is too small - less than 20,000 miles.

The contrast in optimum replacment strategies by minimium average per mile cost and LCC with replacement is apparent While increasing costs reduce optimum life miles under average cost analysis, it is increased by LCC analysis. The difference of course is attributed to the inclusion of replacment cycles in the latter. Table 4.7 shows that under increasing cost conditions low level of output gives a lower minimum LCC increment than the high output since postponement of usage is rewarding.

Figure 4-5 schematically describes the LCC increment in increasing cost environ by level of annual use of transit bus. Notice that under decreasing costs, or net prositive discount rates, the high output level was more economical than the low one. With increasing costs, lower output levels give longer replacement interval; 540,000 miles for 30,000 miles a year compared with 480,000 miles at a rate of 40,000 miles a year.

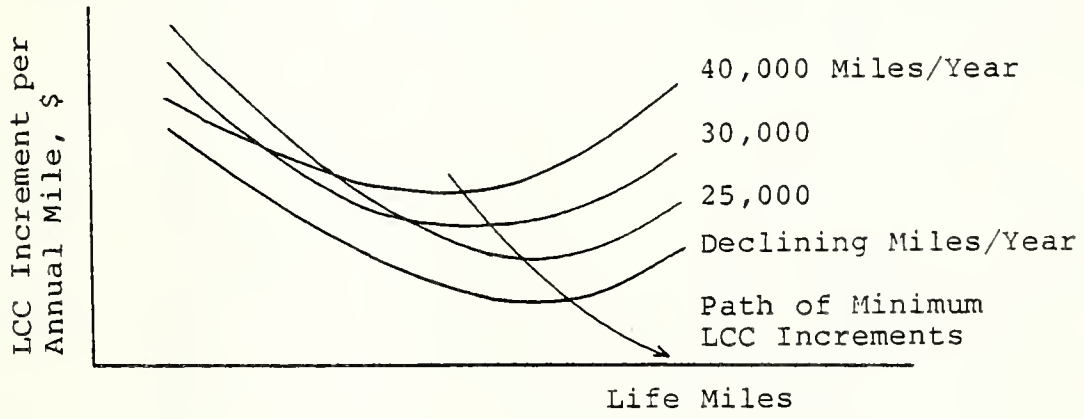


Figure 4.5: LCC Increments Under Increasing Costs by Annual Output

iv. Output Level and Optimum Replacement:

It will be incorrect to conclude from the presentation of LCC analysis above that a low level of output, or a declining use policy that gives a low level of output is desireable and economical in the long run because average annual output per vehicle requirement is usually determined by availability of vehicles, route structure and operating constraints of the transit system. Further, if additional reliability cost is assigned to transit buses to account for age in years, higher output can be found more economical than the low one even when costs are increasing. The optimum replacement level under

increasing cost is also affected by differential growth in costs. If vehicle price is increasing faster than the maintenance and repair costs, the effect will be to increase replacment interval. Rapidly increasing maintenance costs, on the other hand, may justify earlier replacement depending on the share of costs of each component and the differential rates of growth of costs.

Table 4.8 compares the cost of fixed constant miles output levels with the decreasing level policy that gives the same average annual miles by rates of cost increase in percent per year. At 3.2 percent increase, the discount rate of 3.2 percent removes the inflationary cost effect and output levels do not affect per mile cost. Higher discount rates make the "decreasing miles policy" very uneconomical. For instance, a production requirement of 25,000 miles a year by constant mileage policy costs only 82.7 percent of the cost by declining miles policy, if real costs are discounted at ten percent annually. Similarly, 40,000 miles a year can be produced at 86.44 percent of the cost of declining miles by a constant annual use. Even when costs are increasing, constant rate usage is consistently cheaper than the declining one for the same annual average miles.

c. Summary of Results and Conclusion:

In the foregoing replacement analysis of RTA suburban transit buses certain costs that are affected by age and mileage of vehicle, such as maintenance and repairs, fuel, depreciation, and reliability were examined. U-shaped, 20 years cost curves were developed for four levels of bus use; 25,000, 30,000 and 40,000 constant miles per year, and a declining mile per year

TABLE 4-8

PER MILE LCC INCREMENTS BY CONSTANT ANNUAL OUTPUTS
RELATIVE TO A DECLINING RATE OF OUTPUT

Annual Rate of Growth of Costs, %	Output Requirement - Miles per Year per Bus		
	25,000	30,000	40,000
Acquisition Cost, $75,000			
5.00	*	96.57 %	84.52%
3.20	100.00	100.00	100.00
0.00	93.15	95.88	85.54
-6.80	82.70	89.38	86.44
Acquisition Cost,$100,000			
3.20	100.00	100.00	100.00
0.00	93.45	94.69	80.48

* Optimum replacement is greater than 20 years. Since cost figures are limited to this time period, the comparison is not feasible.

alternative that yielded 500,000 miles in 20 years. The last alternative offers above average, 50,000 miles in the first year but only 10,000 miles per year in the last five.

The primary objective of the present study is to determine the number of miles the RTA transit buses should be used, or the replacment interval, so that the per mile future costs of maintenance, fuel, reliability, and replacment are minimized. The cost tables for 20 years bus life were prepared using a six-month survey in the second half of 1977 of repairs and road calls of 288 RTA suburban buses. The following findings refer to the specific cost functions assumed and the current bus price of $75,000.

i. The average cost analysis that minimizes per mile average cost over the life of vehicle indicates smaller replacement cycles with increasing costs in constant dollars (in addition to the increase related to bus age). The life cycle cost analysis, in contrast, suggests longer replacment cycles under increasing cost conditions. The difference in conclusions on optimum replacment cycle reached by these two approaches is attributed to the average cost analysis' failure to consider replacement cost. Further, replacement decision is not affected by annual miles output under average cost analysis. The LCC analysis, however, explicitly considers the level of annual vehicle use. The applicability of LCC analysis to a variety of fleet management problems, such as optimum replacment interval, the output level

of bus annually and over its life time, evaluation of competing bids for equipment of different price, life span and reliability, and replacement vs. rebuilding decisions involving substantial expenditures, is amply illustrated.

ii. If costs are increasing at about five percent annually in constant dollars, the optimum replacment interval for an RTA bus is 480,000 miles over 12 years if used 40,000 miles per year, or 540,000 miles over 18 years at 30,000 miles per year. It should be noted that the reliability costs may have been understated. A significantly higher rate of reliability costs than used in the present study may result in reduction in optimum life of 30,000 to 40,000 miles, or one year.

iii. The effect of increasing, or decreasing real costs of transit bus is to lengthen the replacment miles to minimize per mile LCC increment. A significant change in real costs, five to ten percent annually, is required to change the optimum replacment age of transit bus by one, or two years.

iv. If costs are decreasing, or increasing at a rate lower than the discount rate, it is always economical to increase annual output miles per bus per year. If costs are rising too fast, however, reduction in annual output may prove desirable to save on

LCC of increasing maintenance and replacement. In other words, fast increasing costs suggest a larger fleet with low per vehicle miles.

v. An increase in the price of transit bus without an increase in future cost of maintenance and reliability always increases the optimum replacement interval.

vi. An increase in acquisition cost and resulting increase in depreciation cost always lengthens the replacement interval; an increase in maintenance cost shortens it. A case for increasing subsidy for maintenance can be made from the results of LCC analysis. A higher level of subsidy for maintenance would result in longer optimum replacement interval, as well as lower capital cost. This is contrary to present UMTA guidelines that recommend replacment at a fixed 12 year period, and the CTA preference for a 7 year replacement cycle.

vii. The common industry practice of using new buses more intensively than the older ones results in uneconomic use of resources and higher per mile cost than if the buses are used at a constant annual rate. A declining miles policy examined in the present study, was found uneconomical in every scenario compared with a constant rate of utilization that produced the same number of miles annually. In many

situations, the declining usage required significantly fewer optimum replacement miles than the comparable constant miles policies. The declining use with above average rate of utilization in the early years and a very low rate in the final years should be discouraged on economic ground.

5. REPLACEMENT ANALYSIS OF COMMUTER RAIL LOCOMOTIVES

The objective of this chapter parallels that of the preceding one on transit buses. In the following the procedure for determining the least cost replacement intervals for commuter rail locomotives is described. The major variables affecting locomotive replacment decisions, as for the buses, are acquisition cost, resale value (or depreciation), reliability cost, discount rate, and increase in prices of labor and materials. Based on the experience of suburban rail carriers in the RTA region, the annual use of locomotives is assumed at a constant rate of 40,000 miles. Because of high cost of spares and fixed routes of the rail system, there is little flexibility in annual output per locomotive.

Since many of the conceptual and analytical problems of rolling stock replacment have been already examined in Chapter 3, and the application of LCC analysis to transit bus was described in Chapter 4, the presentation in this chapter is brief. The reader is advised to become familiar with the material presented earlier.

a. Commuter Rail Locomotive Costs:

Data on per mile cost of suburban locomotive operation by equipment age are even scarcer than for the buses. This is in part due to the organization of the rail industry in which suburban passenger system is a small, and often money-losing part. Further, there is a wide difference in equipment, the level of maintenance, and type of service. The repair shops of many carriers also serve non-commuter equipment. Separating the cost of commuter-service in many instances is almost impossible under present record keeping systems. The following outlines the efforts to determine cost data on a comparable level of the transit buses.

i. Maintenance Cost Survey:

After several attempts to dig-out data on the maintenance cost of commuter rail equipment, a survey of repair activities on locomotives and coaches was initiated in September, 1977 for two carriers: (1) the Milwaukee Road with a number of relatively new locomotives, and (2) the Burlington Northern with a significant proportion of older locomotives. Based on in-depth interviews with the representatives of the two railroads, and on-site inspection of their repair facilities, a survey form to record each repair was designed. The survey form presented in Appexdix III was used to note the locomotive, as well as coach maintenance incidences, every week from September, 1977 thru the middle of February, 1978 when efforts were discontinued for the following reasons:

* The time span of the survey was too short compared with the life of locomotives to establish a pattern of repair costs.

* Many of the maintenance activities were performed outside the region, especially certain heavy repairs.

* Current life of locomotives could not be determined because of many overhauls and changes in subsystems. Some of the locomotives were used for freight operations.

* The extent of repair, the labor and materials could not be determined from the available description of repairs. Our attempts to use standard costs for each repair type were not productive.

* There is considerable interchange of parts between locomotives of each carrier. The central exchange units of the railroads do not trace parts movements, nor do they charge specific amount to a specific locomotive, or a coach. They find no justification for assigning costs to individual equipment since costs are internalized for the company as a whole.

* There is little standardization of repair and maintenance activities of the railroads. Since few spare locomotives and coaches are available, especially in the rush hours, the carriers try to maintain high reliability, possibly at high cost. Further, carriers receive premium for better than designated level of on-time performance, while operating deficits are subsidized by the RTA, creating an incentive for over maintenance.

In summary, the survey showed that the present record-keeping systems of the railroads do not permit a reasonable estimation of their commuter system maintenance cost related to equipment age, annual output, type of service, or reliability. No account of mileage or fuel consumption by individual locomotive is kept. Also, it must be recognized that fuel consumption is significantly affected by the number of trailer cars and passenger load.

The primary impression received from the rail system operators was that locomotive life is very long and age has little or no effect on cost of operation. The maintenance staff of the railroads suggested on several occasions that every repair returned the equipment to its original condition and that the older locomotives are just as good, or even better than the new ones in overall economy because of their high standards of repair and workmanship.

Although the reliability record and the quality of service of the commuter rail system in the Chicago metropolitan area is indeed high, much remains to be learned about the true cost of locomotive and coach maintenance. Are we paying too much to maintain the old rolling stock at high performance level? The rail operation is far more complex than the buses; there are many more subsystems. Further, one must consider reliability in terms of all subsystems. A flexible concept of reliability is far more important for locomotives than for transit buses because of high cost of spare units. Maintenance cost of rail equipment could be significantly affected by accepting less than perfect reliability and greater standardization of repairs and maintenance as well as timely replacement.

With reference to the data problems outlined earlier, the simulated cost data by the Electro-Motive Division (EMD) of the General Motors Corp., prepared for the RTA on the new model F40-PH locomotives for use on the Rock Island's Joliet and Blue Island lines was found most suitable for the present research. The simulated cost data include scheduled and unscheduled maintenance cost, including materials, for the F40-PH model over 25 years of life at a rate of 40,000 miles a year. Table 5.1 from the EMD report shows six and twelve year repair cycles. For example, the wheels are replaced every 240,000 miles, while major overhauls are performed at every 480,000 miles, or twelve years. Note that the cost figures are in constant dollars.

Our efforts to have the EMD extend the cost estimates for the locomotive maintenance to 36 or 48 years were not successful. Since most industry sources consider locomotive and coach life to be over 25 years, it was important to estimate the costs to at least 36 years. A recent study commissioned by the RTA estimating the value of rolling stock of the Chicago Northwestern Railroad states

> "For a first generation diesel-electric locomotive, the nominal life-span has been taken as 35 years. While technological changes, such as the advent of electric head end power, have caused locomotives to be retired early others have seen the full life cycle prior to retirement. The Amtrak and railroad experience has been that 35 years or about 4-5 million miles will exact a toll on the structure of the locomotive, and on its trucks, suffient to cause replacment of the unit." (23)

TABLE 5-1

LOCOMOTIVE CALCULATED REPAIR COST 10/09/
INCLUDING UNSCHEDULED MAINTENANCE

3000 HP MODEL F40 PH LOCOMOTIVE
40000. MILES PER YEAR - LABOR RATE = $10.70 / HR.

YEAR	SCHEDULED	UNSCHEDULED	TOTAL
1	7958.	87.	8045.
2	8321.	174.	8496.
3	22799.	349.	23148.
4	20020.	698.	20718.
5	7958.	1396.	9354.
6	31663.	2792.	34456.
7	7958.	130.	8089.
8	24460.	261.	24722.
9	22799.	523.	23322.
10	8321.	1047.	9368.
11	7958.	2094.	10052.
12	124897.	4189.	129086.
13	7958.	174.	8132.
14	8321.	349.	8670.
15	22799.	698.	23497.
16	24460.	1396.	25856.
17	7958.	2792.	10750.
18	31663.	5585.	37249.
19	7958.	261.	8219.
20	20020.	523.	20543.
21	22799.	1047.	23846.
22	8321.	2094.	10416.
23	7958.	4189.	12147.
24	149213.	8378.	157591.
25	7958.	349.	8307.

AVERAGE ANNUAL COST - - - - $ 26563.

AVERAGE ANNUAL COST PER MILE $0.6641

Source: Electro-Motive Division of the General Motors Corp.
A study prepared for the Regional Transportation Authority evaluating the running time, fuel consumption and maintenance and repair costs of locomotives suitable for the Rock Island's commuter service. April 1976.

Although the consultants acknowledge that the suburban service is different from the freight and inter-city passenger trips, no allowance is made in the life span. A survey of eight carriers by the Northeastern Illinois Planning Commission (NIPC) in 1975 indicated an average locomotive life of 31 years.(24)

For the purpose of the present study, the maintenance cost for 25th to 36th years of life of locomotives was estimated by assuming the same rate of growth as that from 13th thru 24th year over the comparable first 12 years. Since the twelve year overhaul cycles assign a large one time cost of over $125,000 to the 12th, 24th and the 36th years, these costs were spread over three years in proportion of 50, 30 and 20 percent. The effect on total cost by this procedure is the same as increasing the resale value, or decreasing the depreciation cost after major overhauls. Table 5.2 shows, among other costs, the annual maintenance cost of commuter locomotive over 36 year life span. Note that the cyclical pattern of costs is maintained since engineering and management considerations do justify fluctuations in maintenance activities.

Currently available data on commuter rail operation do not permit proper evaluation of costs and optimum replacment analysis of the rolling stock based on local experience. In fact, analysis of coach replacement had to be dropped completely for lack of basic data for individual units and respective age in total miles.

TABLE 5-2

ANNUAL MILES, MAINTENANCE, DEPRECIATION, RELIABILITY AND TOTAL COST OF COMMUTER RAIL LOCOMOTIVES

YEAR	MILES	MAINT.$	DEPR.$	REL.$	COST/YR.	AVE.COST
1	40000.	8045.	194386.	220.	202651.	5.0663
2	40000.	8496.	52874.	343.	61713.	3.3045
3	40000.	23148.	47842.	472.	71462.	2.7985
4	40000.	20718.	43289.	605.	64613.	2.5027
5	40000.	9354.	39170.	746.	49270.	2.2485
6	40000.	34456.	35442.	894.	70793.	2.1688
7	40000.	8089.	32069.	1053.	41211.	2.0061
8	40000.	24722.	29018.	1222.	54962.	1.9271
9	40000.	23322.	26256.	1405.	50983.	1.8546
10	40000.	9368.	23758.	1605.	34731.	1.7560
11	40000.	10052.	21497.	1824.	33373.	1.6722
12	40000.	64543.	19451.	2067.	86061.	1.7121
13	40000.	46858.	17600.	2338.	66796.	1.7089
14	40000.	34487.	15925.	2643.	53055.	1.6816
15	40000.	23497.	14410.	2988.	40895.	1.6376
16	40000.	25856.	13039.	3381.	42276.	1.6013
17	40000.	10750.	11798.	3833.	26380.	1.5459
18	40000.	37249.	10675.	4353.	52277.	1.5326
19	40000.	8219.	9659.	4957.	22835.	1.4820
20	40000.	20549.	8740.	5660.	34949.	1.4516
21	40000.	23846.	7908.	6482.	38236.	1.4280
22	40000.	10416.	7156.	7446.	25017.	1.3915
23	40000.	12147.	6475.	8580.	27202.	1.3606
24	40000.	78795.	5859.	9919.	94572.	1.4024
25	40000.	55584.	5301.	11502.	72387.	1.4187
26	40000.	41055.	4797.	13377.	59229.	1.4211
27	40000.	28196.	4340.	15602.	48138.	1.4130
28	40000.	31027.	3927.	18247.	53201.	1.4101
29	40000.	12900.	3553.	21393.	37847.	1.3941
30	40000.	44700.	3215.	25141.	73056.	1.4085
31	40000.	9863.	2909.	29607.	42379.	1.3972
32	40000.	24659.	2632.	34935.	62226.	1.4022
33	40000.	28615.	2382.	41293.	72290.	1.4144
34	40000.	29500.	2155.	48886.	79542.	1.4313
35	40000.	14576.	1950.	57957.	74483.	1.4436
36	40000.	86675.	1765.	68797.	157236.	1.5127
SUM =	1440000.	983332.	733222.	461773.	2178317.	

ii. Depreciation Cost:

Although the locomotives, in general, have a better and larger resale market than the transit buses, the design of commuter rail rolling stock make them unsuitable for freight, or inter-city service. The resale value of relatively new locomotives, therefore is only theoretical, or a book value. A convex declining curve, representing the resale value of locomotives, was developed that gave 26 percent depreciation in the first 40,000 miles of service. In the later years the rate declines rapidly and is almost zero in the 36th year of life. The depreciation cost in year t, D(t), is given by

$$D(t) = MP_{t-1} - MP_t$$

where $MP_t = MP_0 \cdot (\exp(-0.2-(0.1\ t)))$

MP_0 = Purchase price of new locomotive in 1977, i.e. \$750,000.

and t = Age of locomotive in years.

Annual depreciation costs for locomotives are given in Table 5.2.

iii. Reliability Cost:

Unlike road call data on transit buses, little information is available on in-service breakdown of locomotives. The need for excess fleet to substitute units in repair could not be determined. In fact, the Burlington Northern officials said that they have no spares and must use all the units during peak hours. All repairs, therefore, are made in off-peak hours. The Milwaukee and Burlington Northern officials indicated that there are no reliability problems and no costs associated

to in-service breakdown, except in very special situations. The railroad officials could not assign reliability penalty to the age of locomotives, so long as proper maintenance procedure were followed.

Without reliability costs, the data on maintenance cost and depreciation suggest locomotive life of over 36 years on the basis of per mile average cost. Further, local experience does indicate high maintenance and breakdown problems of older equipment. The Burlington Northern with older equipment is being paid more per mile cost for new off-peak service by the RTA than the Milwaukee Road with relatively newer locomotives. Our brief survey of maintenance also indicated relatively more maintenance activity at the Burlington Northern than at the Milwaukee Road.

To compensate for the high maintenance related to equipment age, total reliabilty cost equal to about one-half the cost of maintenance was assesed over a span of 36 years. In addition, for each year of service of the locomotive $100 were allocated to road call costs. The relaiability cost for locomotives at any age period t, R(t), was computed by the formula

$$R(t) = (\exp(+0.175\ t)\ 100) + (100\ t)$$

where t = Age of locomotive in years.

iv. Average Cost:

Table 5.2 shows that the per mile cumulative average cost of locomotive maintenance, depreciation and reliability, defined earlier, is minimum in the 23rd year of use, or 920,000 miles, and is equal to $1.36. At this point, a decision must be made whether the overhaul cost of nearly $150,000 should be incurred. On the basis of average costs, such expenditure is not justified and the locomotive must be replaced.

b. Commuter Rail Locomotive Replacement:

In this section the locomotive replacement decision is examined using the LCC approach that explicitly considers replacements under four conditions: one, cost increase equal to discount rate; two, discount rate of 3.2 percent and more; three, cost increase of 5.0 percent and more; and four, sudden increase in acquisition cost of locomotive of 33.3 percent. Table 5.3 lists the LCC increments by selected rates of cost increase for one thru 36 annual replacement cycles for locomotives used 40,000 miles a year constant rate.

i. Cost Increase Equal To Discount Rate:

The cost increase of maintenance, depreciation, and reliability at the same annual rate as the discount rate i.e., 3.2 percent, implies that the net time value of money is zero. The minimum average cost also minimizes the LCC increment. In this circumstance, the locomotive should be replaced every 23 years, or 920,000 miles at an average annual per mile cost of $1.36.

ii. Discount Rate of 3.2 Percent and More:

If prices increase only as much as inflation, in other words, costs do not increase in constant dollars, present dollars are worth more in the future. It pays to postpone expenditures and earn positive dividends. The net effect of positive discount rates is to reduce the life cycle cost increments and increase optimum replacement cycle.

A social discount rate of 3.2 percent, in the absence of cost increase in constant dollars, indicates that $45.42 in 1977 can support an annual output of one mile to infinity, for a locomotive replaced every 23 years, or 920,000 miles, the same as if the real rate of price increase were of 3.2 percent.

If costs decline by 6.8 percent annually, the effective discount rate of 10 percent reduces the current investment requirement for one mile annual output to infinity to $16.44. The optimum replacement interval increases to 32 years, or 1,280,000 miles at 40,000 miles a year.

iii. Cost Increase of 5.0 Percent or More:

Increasing cost not only makes maintenance more expensive but also increase the price of replacement. However, as observed earlier, a significant rate of cost increase is genera required to shift the minimum cost replacement life miles. A cost increase of 5 percent, combined with 3.2 percent discount rate, increases the annual cost but suggests replacement every 23 years, the same as if no cost increase.

Table 5-3

LIFE CYCLE COST INCREMENTS FOR COMMUTER RAIL LOCOMOTIVES BY ANNUAL RATES OF PRICE INCREASE

	Life Miles	Per Mile 9%	Average Annual Cost 5%	0%, $750,000	0%,$1,000,000	-6.8%
1	40000.	5726797920.	4601.9180	155.7869	205.5980	46.1715
2	80000.	3687601660.	2987.2710	102.4898	134.4626	32.2574
3	120000.	3158023170.	2540.6111	87.1444	112.7556	27.0669
4	160000.	2761613570.	2252.8206	78.2218	100.3759	25.0350
5	200000.	2460846590.	2017.7891	70.6612	90.5446	22.8750
6	240000.	2494829310.	1983.1279	68.1671	88.3914	22.1015
7	280000.	2300480000.	1832.4407	63.4419	80.3703	20.8250
8	320000.	2202707460.	1758.3547	61.0806	76.9510	20.1590
9	360000.	2097078780.	1685.5020	58.9484	73.9281	19.5797
10	400000.	1873384190.	1560.4763	56.1680	70.3811	18.6860
11	440000.	1915133440.	1526.9954	53.8165	67.3588	18.3118
12	480000.	1916753920.	1550.7039	54.6743	67.0221	18.4090
13	520000.	1976227580.	1566.9011	54.4649	66.8309	18.3093
14	560000.	1834356990.	1508.3694	53.6781	65.8146	18.1132
15	600000.	1902094080.	1503.5942	52.5043	64.8057	17.8597
16	640000.	1887067650.	1477.7389	51.5316	62.8361	17.8519
17	680000.	1779772570.	1415.2024	50.1258	60.8668	17.3843
18	720000.	1707948030.	1385.2476	49.7111	60.1179	17.2811
19	760000.	1744609790.	1367.5342	48.4615	58.5601	17.0618
20	800000.	1492806400.	1271.5491	47.6783	57.4913	16.9177
21	840000.	1551196160.	1279.1794	47.0579	56.6072	16.8028
22	880000.	1565626110.	1263.6970	46.1726	55.4763	16.6006
23	920000.	1507366400.	1228.3284 *	45.4174 *	54.4926	16.5411
24	960000.	1477573380.	1242.2183	46.1854	55.0475	16.6034
25	1000000.	1492734980.	1249.9019	46.4366	55.0996	16.6091
26	1040000.	1722340350.	1325.2795	46.4140	54.6908	16.5877
27	1080000.	1649448960.	1302.9131	46.1913	54.4935	16.5488
28	1120000.	1466536700. *	1239.7063	46.0726	54.2112	16.5222
29	1160000.	1670911230.	1295.2820	45.7117	53.8966	16.4761
30	1200000.	1497799680.	1254.2202	45.9226	53.7831	16.4810
31	1240000.	1709794050.	1305.5754	45.6669	53.5714	16.4492
32	1280000.	1496863490.	1251.0120	45.7065	53.2829 *	16.4418 *
33	1320000.	1732688130.	1323.4226	45.8777	53.5333	16.4448
34	1360000.	1492080380.	1261.8892	46.1301	53.4716	16.4537
35	1400000.	1708616700.	1338.3318	46.3054	53.5392	16.4579
36	1440000.	1560491790.	1319.7403	47.4258	54.5577	16.5196

* Minimum cost replacement age.

An increase of 8 percent annually, though raises the minimum average cost retirement age to 28 years, or 1,120,000 miles.

iv. Effect of Sudden Price Increases:

If the cost of locomotive increases to a million dollars from $750,000, the depreciation costs increase relative to maintenance cost. The net effect on minimum LCC increment is to lengthen the replacement cycle. Table 5.3 shows that without annually increasing costs, the increased price of locomotive results in optimum replacement age of 32 years, or 1,280,000 miles.

c. Summary of Results and Conclusion - Locomotive Replacement

In the foregoing replacement analysis of commuter rail locomotives, the costs of maintenance, depreciation, and reliability were estimated from indirect sources since a four-month survey of maintenance failed to identify pattern of costs related to locomotive age. Annual total costs for one thru 36 years of life of locomotive were computed based on 40,000 miles annual output. The LCC increments for selected cost increase rates from -6.8 percent to 8.0 percent were examined and corresponding minimum cost replacement periods were identified.

The following summarizes the important results of locomotive replacement analysis:

i. For a commuter rail locomotive used at a rate of 40,000 miles annually, the aminimum average per mile cost, including maintenance, reliability and depreciation, is $1.36 in the 23rd year of life, or 920,000 life miles. This result is the same as for a cost increase of 3.2 percent and a discount rate of the same amount.

ii. If a moderate cost increase of 5 percent per year in constant dollars is assumed as an industry norm, the locomotives should be replaced every 23 years while minimizing the LCC increment. An increase of 8 percent per year, however, requires the locomotives to be used for 28 years, or 1,120,000 miles.

iii. The declining real cost of 6.8 percent, or a discount rate of 10 percent increases the minimum cost replacement age of locomotives to 32 years, or 1,280,000 life miles.

iv. A sudden increase in the acquisition price of locomotives to a million dollars will require to lengthen the replacment cycle to 32 years, or 1,280,000 life miles.

v. Despite attempts to make the figures on locomotive operation costs as realistic as possible, the lack of confidence in the figures, especially their relevance to the Chicago region is acknowledged. The maintenance cost data, supplied by the Electro-Motive Division of General Motors Corp. that manufactures the locomotives now in service, appear too low compared with

actual cost experience. If actual support costs are indeed higher than suggested by the EMD estimates, the optimum locomotive life may reduce significantly from 23 years.

Understanding of the reliability cost of rail equipment by age, as manifested in high cost, or in-service breakdowns, is ciritically lacking. The present effort, however, provides a groundwork for replacement analysis as more reliable data become available. The results indicates significant management analysis application of the LCC with replacement approach and better understanding of the forces affecting replacement/rebuilding decisions.

6. FUTURE WORK PROGRAM IN LCC REPLACEMENT ANALYSIS:

The LCC analysis presented in this study covers most issues in determining the output level, replacement interval, rehabilitation and selection of bids of transit buses. Many basic analytical and mathodological questions have been addressed and a groundwork for decision-making in real life environs has been established. The biggest hurdle, in practical application of LCC analysis, is the realistic appraisal of costs associated with use and age of vehicles. Although the available data base was adequate for the present exploratory research, significantly improved understanding and measurement of costs associated with reliability standards are necessary.

The present study assumed constant annual changes in costs that may not be found in real life situations. It is interesting to examine cyclical or stochastic growth in costs of maintenance and purchase price. The need for more realistic cost scenarios cannot be overemphasized.

Recent UMTA efforts to collect and analyse bus cost data are indicative of the recognized need for a reliable bus cost data base (25). The LCC analysis based on actual costs can be employed to many management problems for the transit industry, such as replacement interval for the vehicle and its subsystems, selection of bids, optimum maintenance level, relative shares of subsidy for capital and maintenance costs, and evaluation of expensive overhauls and rebuildings compared with replacement.

Many of the issues addressed in LCC analysis are of national importance, such as subsidy for maintenance versus capital projects. The present study substantiates the obvious that the transit agencies financed relatively heavily for new equipment compared with maintenance, may tend to undermaintain and underuse their rolling stock. Evaluation of the advanced-design, the transbus and other improved buses on the basis of life cycle analysis, as presented in this paper, would be helpful in formulating criteria in financing and subsidizing transit costs.

F O O T N O T E S

(1) Simpson and Curtin, Public Transportation Systems in Northeastern Illinois, Summary, 1975. Prepared for the Regional Transportation Authority.

(2) Road call cost refers to the cost of servicing vehicles that breaks down during service on the road. Typically, one tow truck and two people must be sent to the scene.

(3) The LCC analysis approach used in this study does not require any assumption of depreciation. If the total purchase price is assigned to the year of procurement, optimum life span of equipment is extended.

(4) Booz-Allen Applied Research and Simpson and Curtin, Transbus Operational, Passenger, and Cost Impact, July 1976. Prepared for the U. S. Urban Mass Transportation Administration, Washington, D.C. Transbus Document #TR-75-002.

(5) Vehicle Series Cost Report is the Chicago Transit Authority's regular publication describing certain maintenance and repair costs by bus series and garages for 13 four-week periods a year.

(6) Advanced Management Systems, Inc., Life Cycle Costing for Current Rohr and AM General Buses and General Motors RTS-II Bus, McLean, Va., Table 2, July 1976. UMTA-VA-06-0039-76-1.

(7) Ibid., Advanced Management Systems, Inc., 1976.

(8) Refer to GSA publication in Bibliography. Also refer to Section 3.c for a review of relevant literature and an outline of history of LCC analysis.

(9) John E. Williams, "Life Cycle Costing, an Overview," A paper presented at the AIIE/AACE Joint Conference on Life Cycle Costing: A New Approach to Systems, Washington, D.C., October 5-6, 1977, p. 30.

(10) Life Cycle Costing Workbook, General Service Administration, Washington, D.C., February, 1977.

(11) D. E. Burkarte, "RIW as a Practical LCC Procurement Technique," Rockwell-Collins, Cedar Rapids, Iowa. A paper presented at the AIIE/AACE Joint Conference on Life Cycle Costing: A New Approach to Systems, Washington, D.C. October 5-6, 1977, p. 18.

(12) William B. Tye, "A Capital Grant as a Subsidy Device: The Case Study of Urban Mass Transportation," The Economics of Federal Subsidy Programs, the Joint Economic Committee, the U. S. Congress, Washington, D.C., 1973, pp. 796-826.

(13) Edward C. Posner, "Life Cycle Costing with a Discount Rate," Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California,. A paper presented at the annual conference of the Operations Research Society of America, Philadelphia, 1976,p.33.

(14) J. Edward Anderson, "Life Cycle Cost and Reliability Allocation in Automated Transit Systems," High Speed Ground Transportation, Vol. 11, No. 1, Spring 1977, pp. 1-18.

(15) Op. cit., Booz-Allen Applied Research and Simpson and Curtin, July, 1976.

(16) Passenger Transport, American Public Transit Association, September 9, 1977, pp. 10.

(17) H. R. Kain, G. J. Marks, and L. A. Staszak, Life Cycle Costing for Current Rohr and AM General Motors RTS-II Bus, Advanced Management Systems, Inc., McLean, Va., July, 1976, p. 23.

(18) H. Chaput, P. "Ottawa-Carleton Transit Procedure for evaluation of Tenders," A paper presented at the American Transit Association Spring Conference, Washington, D.C., May 22, 1974, p. 16.

(19) William A. Perkins, Jr., Vehicle Maintenance and Operation Reporting System, Regional Transportation Authority, Chicago, Illinois, May, 1977.

(20) Ibid., Vehicle Series Cost Report, the Chicago Transit Authority June 12, 1976.

(21) Op. Cit., William B. tye, 1973.

(22) The maximum replacement age for a transit bus was determined 20 years, a priori, reflecting an opinion that a 20 year old bus is ready for retirement, irrespective of the mileage.

(23) Michael R. Weinman and Carl R. Englund, Jr., & Son, "Explanation of Estimated Life on Locomotives," September, 1977. Prepared for The RTA.

F O O T N O T E S (CONTINUED)

(24) Barry R. Knight, "Standard Economic Lifetimes: A suggested Method for Assessing Transit Capital Needs," Northeastern Illinois Planning Commission, Chicago, IL., July, 1975, p. 14.

(25) In 1977 the Urban Mass Transportation Authority awarded a contract to the Metropolitan Suburban Bus Authority in New York to study the cost of bus maintenance over many years life span. Refer to Passenger Transport, American Public Transit Association, September 9, 1977. pp. 10.

B I B L I O G R A P H Y

Advanced Management Systems, Inc., Life Cylce Costing for Current Rohr and AM General Buses and General Motors RTS-II Bus, Mclean, Va., Table 2, July, 1976. UMTA-VA-06-0039-76-1.

Anderson, Edward J., "Life-Cycle Cost and Reliability Allocation in Automated Transit Systems," High Speed Ground Transportation, Vol. 11, No. 1, Spring 1977, pp.1-18.

Booz - Allen Applied Research and Simpson and Curtin, Transbus Operational, Passenger, and Cost Impact, July, 1976. Prepared for the U.S. Urban Mass Transportation Administration, Washington, D.C. Transbus Document #TR-75-002.

Burkarte, D. C. "RIW as a Practical LCC Procurement Technique," Rockwell - Collins, Cedar Rapids, Iowa. A paper presented at the AIIE/AACE Joint Conference on Life Cycle Costing A New Approach to Systems, Washington, D.C. October 5-6, 1977, p. 18.

Posner, Edward C., "Life Cycle Costing with a Discount Rate," Jet Propulsion Laboratory, Calfiornia Institute of Technology, Pasadena, California. pp. 33. A paper presented at the annual conference of the Operations Research Society of America, Philadelphia, 1976.

Tye, William B., "A Capital Grant as a Subsidy Device: the case study of Urban Mass Transportation," The Economic of Federal Subsidy Programs, the Joint Economic Committee, the U. S. Congress, Washington, D.C. 1973, pp. 796-826.

Life Cycle Costing Workbook, U. S. General Services Administration, Washington, D.C. February, 1977.

Williams, John E., "Life Cycle Costing, an Overview", A paper presented at the AIIE/AACE Joint Conference on Life Cycle Costing: A New Approach to Systems, Washington, D.C., October 5-6, 1977, p. 30.

APPENDIX I

COMPUTER PROGRAM FOR LIFE CYCLE COST REPLACEMENT ANALYSIS (MAX. 20 YEARS LIFE)

```
      INTEGER T1,T2
      INTEGER NOT(2)/'   ','NOT'/
      REAL INFLR,MAINT(50),MILES(50),MILEYR,RESALE(50),RELYC(50),
     *LCCI,LCCF,LCC,SPECA(50),DEPR(50),YCOST(50),COSTYR(50)
      REAL QMILES(50),PMAINT(50),RODCOP(50),FUELCP(50),RESMIL(50),
     *RMAINT(50),RODCOR(50),FUELCR(50),ZMILES(50),TOTMAN(50),
     *TOTROD(50),TOTFUL(50),TCOST(50),RATIO(50),TOTAL(50),AVERAG(50)
62000 FORMAT(/1X,I3,10F10.0)
      WRITE(9,62001)
62001 FORMAT(/1X,'INPUT DATA--ANNUAL COSTS BY ANNUAL MILES'///1X,T16,
     *'M A I N   V E H I C L E '
     */1X,T2,'YR.',T9,'MILES',T19,'MAINT.$',T29,'RD.CALL $',
     *T40,'FUEL $'/1X,50('_'))
      DO 61000 I=1,20
      READ(11,1100)QMILES(I),PMAINT(I),RODCOP(I),FUELCP(I)
1100  FORMAT(4F8.0)
      TOTMAN(I)=(PMAINT(I)+FUELCP(I))
61000 WRITE(9,62000)I,QMILES(I),PMAINT(I),RODCOP(I),FUELCP(I)
      COMMON E
      E=2.71828
      READ(1,100) PRICE,ALPHA1,ALPHA2,ALPHA3,ALPHA4,ALPHA5,MILEYR
100   FORMAT(7F10.2)
      WRITE(9,1000) PRICE,ALPHA1,ALPHA2,ALPHA3,ALPHA4,ALPHA5,MILEYR
1000  FORMAT(/1X,'SPECIFIED PURCHASE PRICE OF NEW VEHICLE IS',F10.2/
     *1X,'SPECIFIED ALPHA1 IS ',F10.4/
     *1X,'SPECIFIED ALPHA2 IS ',F10.4/
     *1X,'SPECIFIED ALPHA3 IS ',F10.4/
     *1X,'SPECIFIED ALPHA4 IS ',F10.4/
     *1X,'SPECIFIED ALPHA5 IS ',F10.4/
     *1X,'SPECIFIED VEHICLE YEARLY MILEAGE IS ',F10.0/)
      READ(1,200) ISMILE,ISMAIN,ISRESL,ISRELY
200   FORMAT(4I1)
      WRITE(9,2000) NOT(ISMILE+1),NOT(ISMAIN+1),NOT(ISRESL+1),
     *NOT(ISRELY+1)
2000  FORMAT(1X,'MILES PER YEAR WERE ',A3,' READ IN AS A VECTOR'/
     *1X,'MAINTAINENCE COSTS WERE ',A3,' READ IN AS A VECTOR'/
     *1X,'RESALE VALUES WERE ',A3,' READ IN AS A VECTOR'/
     *1X,'RELIABILITY COSTS WERE ',A3,' READ IN AS A VECTOR'/
     *1X,'SPECIAL APPRECIATION COSTS ARE ALWAYS READ IN AS A VECTOR'/)
      READ(1,300) T1,T2
300   FORMAT(2I2)
      WRITE(9,3000) T1,T2
3000  FORMAT(1X,'LIFE CYCLE STARTS WITH YEAR ',I3/
     *1X,'LIFE CYCLE ENDS WITH YEAR ',I3/)
400   FORMAT(F10.2)
60000 FORMAT(1X,I3,F10.2)
      DO 50 I=T1,T2
      IF(ISMILE.EQ.0) READ(10,400) MILES(I)
      IF(ISMILE.EQ.1) MILES(I)=MILEYR
50    CONTINUE
      DO 10 I=T1,T2
      IF(ISMAIN.EQ.0) READ(2,400) MAINT(I)
      IF(ISMAIN.EQ.0)MAINT(I)=TOTMAN(I)
      IF(ISMAIN.EQ.1) CALL COMPM(MAINT(I),1)
10    CONTINUE
      DO 20 I=T1,T2
      IF(ISRESL.EQ.0) READ(3,400) RESALE(I)
      TMILES=0.0
```

```
      DO 29 J=T1,I
29    TMILES=TMILES+MILES(J)
      IF(ISRESL.EQ.1) CALL COMPD(RESALE(I),I,TMILES,ALPHA3,PRICE)
20    CONTINUE
      DO 38 I=T1,T2
      YCOST(I)=PRICE-RESALE(I)
      IF(I.EQ.1) GO TO 37
      DEPR(I)=YCOST(I)-YCOST(I-1)
37    DEPR(1)=YCOST(1)
38    CONTINUE
      DO 30 I=T1,T2
      IF(ISRELY.EQ.0) READ(4,400) RELYC(I)
      IF(ISRELY.EQ.0)RELYC(I)=(.1*PMAINT(I))+RODCOP(I)
      IF(ISRELY.EQ.1) CALL COMPR(RELYC(I),I)
30    CONTINUE
      WRITE(9,80000)
80000 FORMAT(/1X,'VECTOR OF SPECIAL DEPRECIATION'/1X,'YEAR'/)
      DO 40 I=T1,T2
      READ(8,400) SPECA(I)
40    WRITE(9,80000) I,SPECA(I)
      WRITE(9,90000)
90000 FORMAT(1H1,/20X,'ANNUAL MILES, MAINTENANCE, DEPRECIATION, RELI
     *ITY AND TOTAL COST'///20X,T22,'YEAR',T31,'MILES',T41,'MAINT.$'
     *T51,'DEPR.$',T61,'REL.$',T69,'COST/YR.',T79,'AVE.COST'/)
91000 FORMAT(20X,I2,5X,5(F8.0,2X),F8.4)
      TMILES=0.0
      CUMCOS=0.0
      DO 92000 I=T1,T2
      COSTYR(I)=MAINT(I)+DEPR(I)+RELYC(I)
      TMILES=TMILES+MILES(I)
      CUMCOS=CUMCOS+COSTYR(I)
      AVERAG(I)=CUMCOS/TMILES
92000 WRITE(9,91000)I,MILES(I),MAINT(I),DEPR(I),RELYC(I),COSTYR(I),
     *AVERAG(I)
      SUMMIL=0.0
      DO 93 I=T1,T2
93    SUMMIL=SUMMIL+MILES(I)
      SUMMAN=0.0
      DO 94 I=T1,T2
94    SUMMAN=SUMMAN+MAINT(I)
      SUMDEP=0.0
      DO 95 I=T1,T2
95    SUMDEP=SUMDEP+DEPR(I)
      SUMREL=0.0
      DO 96 I=T1,T2
96    SUMREL=SUMREL+RELYC(I)
      SUMTOT=0.0
      DO 97 I=T1,T2
97    SUMTOT=SUMTOT+COSTYR(I)
      WRITE(9,98)SUMMIL,SUMMAN,SUMDEP,SUMREL,SUMTOT
98    FORMAT(//20X,'SUM   =',1X,5(F8.0,2X))
      WRITE(9,120)
120   FORMAT(/1X,T2,'YEAR',T15,'MAINT.',T25,'   DEPRE.',
     *T36,'   RELIAB.',T49,'   SP.DEP.'/1X,T12,'   FACTOR',
     *T25,'   FACTOR',T38,'   FACTOR',T49,'   FACTOR'/1X,59('_'))
      WRITE(6,101)
101   FORMAT('1','LIFE CYCLE COST (LCC)'///1X,T2,'YR.',T7,'LIFE ',
     *T17,'MAINT.',T25,'PURCH.',T34,'TOTAL',T43,'RELB.',
```

```
     *T51,'SPECIAL',T62,'LCC',T71,'LCC',T78,'AVE. YR.',T87,'PER MILE',
     */1X,T7,'MILES',T17,'FUEL',T25,'PRICE',T34,'DEPREC.',T43,'COST',
     *T51,'DEPREC.',T60,'INCRMNT.',T79,'MILES',T87,'LCC INC.'
     */1X,94('_'))
      DO 90 I=T1,T2
      KM=0
      KD=0
      KR=0
      KS=0
      PVM=0.0
      PVFPP=0.0
      PVD=0.0
      PVRC=0.0
      PVSA=0.0
      LCCI=0.0
      LCC=0
      TOTMIL=0.0
      YMILES=0.0
      QINDEX=0.0
      FLCCM=0.0
      CYLMAN=0.0
      FLCCD=0.0
      DEPCYL=0.0
      FLCCR=0.0
      RELCYL=0.0
      FLCCS=0.0
      SPACYL=0.0
      KXM=0
      KXR=0
      KXD=0
      KXS=0
      EXTRAM=0.0
      EXTRAD=0.0
      EXTRAR=0.0
      EXTRAS=0.0
      PVFPP=(E**(ALPHA3*I))*PRICE
      DO 60 K=1,500
      KM=(K*I)+I
      IF(KM.GT.500) GO TO 61
      FLCCM=FLCCM+(E**((ALPHA2-ALPHA1)*K*I))
      GO TO 60
61    KXM=500-(K*I)
      GO TO 601
60    CONTINUE
601   FLCCM=FLCCM+1
      IF(KXM.EQ.0) GO TO 600
      DO 602 J=1,KXM
602   EXTRAM=EXTRAM+(E**((ALPHA2-ALPHA1)*J))*MAINT(J)
      EXTRAM=EXTRAM*(E**((ALPHA2-ALPHA1)*(500-KXM)))
600   CONTINUE
      DO 603 J=T1,I
603   CYLMAN=CYLMAN+(E**((ALPHA2-ALPHA1)*J))*MAINT(J)
      PVM=(CYLMAN*FLCCM)+EXTRAM
      PVM=PVM/500
      DO 70 K=1,500
      KD=(K*I)+I
      IF(KD.GT.500) GO TO 71
      FLCCD=FLCCD+(E**((ALPHA3-ALPHA1)*K*I))
```

```
      GO TO 70
71    KXD=500-(K*I)
      GO TO 701
70    CONTINUE
701   FLCCD=FLCCD+1
      IF(KXD.EQ.0) GO TO 700
      DO 702 J=1,KXD
702   EXTRAD=EXTRAD+(E**((ALPHA3-ALPHA1)*J))*DEPR(J)
      EXTRAD=EXTRAD*(E**((ALPHA3-ALPHA1)*(500-KXD)))
700   CONTINUE
      DO 703 J=T1,I
703   DEPCYL=DEPCYL+(E**((ALPHA3-ALPHA1)*J))*DEPR(J)
      PVD=(DEPCYL*FLCCD)+EXTRAD
      PVD=PVD/500
      DO 80 K=1,500
      KR=(K*I)+I
      IF(KR.GT.500) GO TO 81
      FLCCR=FLCCR+(E**((ALPHA4-ALPHA1)*K*I))
      GO TO 80
81    KXR=500-(K*I)
      GO TO 801
80    CONTINUE
801   FLCCR=FLCCR+1
      IF(KXR.EQ.0) GO TO 800
      DO 802 J=1,KXR
802   EXTRAR=EXTRAR+(E**((ALPHA4-ALPHA1)*J))*RELYC(J)
      EXTRAR=EXTRAR*(E**((ALPHA4-ALPHA1)*(500-KXR)))
800   CONTINUE
      DO 803 J=T1,I
803   RELCYL=RELCYL+(E**((ALPHA4-ALPHA1)*J))*RELYC(J)
      PVRC=(RELCYL*FLCCR)+EXTRAR
      PVRC=PVRC/500
      DO 190 K=1,500
      KS=(K*I)+I
      IF(KS.GT.500) GO TO 191
      FLCCS=FLCCS+(E**((ALPHA5-ALPHA1)*K*I))
      GO TO 190
191   KXS=500-(K*I)
      GO TO 1901
190   CONTINUE
1901  FLCCS=FLCCS+1
      IF(KXS.EQ.0) GO TO 1900
      DO 1902 J=1,KXS
1902  EXTRAS=EXTRAS+(E**((ALPHA5-ALPHA1)*J))*SPECA(J)
      EXTRAS=EXTRAS*(E**((ALPHA5-ALPHA1)*(500-KXS)))
1900  CONTINUE
      DO 1903 J=T1,I
1903  SPACYL=SPACYL+(E**((ALPHA5-ALPHA1)*J))*SPECA(J)
      PVSA=(SPACYL*FLCCS)+EXTRAS
      PVSA=PVSA/500
      LCCI=PVM+PVD+PVRC+PVSA
      LCC=PRICE+LCCI
      DO 130 J=T1,I
130   TOTMIL=TOTMIL+MILES(J)
      YMILES=TOTMIL/I
      QINDEX=LCCI/YMILES
      WRITE(6,201)I,TOTMIL,PVM,PVFPP,PVD,PVRC,PVSA,LCCI,LCC,
     *YMILES,QINDEX
```

```
201   FORMAT(/1X,I2,9F9.0,F15.6)
      WRITE(9,110)I,FLCCM,FLCCD,FLCCR,FLCCS
110   FORMAT(/1X,I2,8X,4F12.7)
90    CONTINUE
      STOP
      END
```

APPENDIX II.A

ANNUAL VARIABLE COSTS OF TRANSIT BUS USED 25,000 MILES A YEAR

Costs by Annual Percent Growth Rates

		0.0%		1.5%		3.2%		5.0%		10.0%	
YEAR	MILES	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST
1	25000.	20347.	0.8139	20404.	0.8161	20469.	0.8188	20540.	0.8216	20742.	0.8297
2	25000.	17121.	0.7494	17642.	0.7609	18252.	0.7744	18921.	0.7892	20911.	0.8331
3	25000.	15414.	0.7051	16124.	0.7223	16967.	0.7425	17909.	0.7649	20807.	0.8328
4	25000.	13819.	0.6670	14674.	0.6884	15706.	0.7139	16879.	0.7425	20616.	0.8308
5	25000.	11684.	0.6271	12594.	0.6515	13711.	0.6808	15003.	0.7140	19264.	0.8187
6	25000.	10050.	0.5896	10996.	0.6162	12177.	0.6486	13566.	0.6854	18312.	0.8043
7	25000.	9188.	0.5578	10205.	0.5865	11494.	0.6216	13038.	0.6620	18502.	0.7952
8	25000.	9119.	0.5337	10282.	0.5646	11780.	0.6028	13605.	0.6473	20296.	0.7972
9	25000.	8859.	0.5138	10140.	0.5469	11816.	0.5883	13894.	0.6371	21790.	0.8055
10	25000.	8715.	0.4973	10126.	0.5327	12002.	0.5775	14369.	0.6309	23691.	0.8197
11	25000.	9914.	0.4881	11692.	0.5268	14096.	0.5763	17183.	0.6360	29782.	0.8535
12	25000.	8351.	0.4753	9998.	0.5163	12261.	0.5691	15217.	0.6337	27727.	0.8748
13	25000.	7686.	0.4624	9341.	0.5053	11651.	0.5612	14723.	0.6333	28202.	0.8943
14	25000.	7501.	0.4508	9254.	0.4956	11741.	0.5546	15106.	0.6284	30419.	0.9173
15	25000.	7702.	0.4413	9646.	0.4883	12448.	0.5509	16336.	0.6300	34520.	0.9482
16	25000.	8283.	0.4344	10529.	0.4841	13821.	0.5510	18433.	0.6367	41024.	0.9915
17	25000.	8819.	0.4296	11379.	0.4824	15192.	0.5543	20630.	0.6478	48267.	1.0468
18	25000.	9612.	0.4271	12591.	0.4836	17098.	0.5615	23641.	0.6644	58147.	1.1178
19	25000.	10427.	0.4265	13865.	0.4873	19151.	0.5723	26961.	0.6861	69712.	1.2057
20	25000.	11219.	0.4277	15143.	0.4932	21276.	0.5862	30495.	0.7128	82894.	1.3112
SUM =	500000.	213828.		246624.		293110.		356416.		655624.	

APPENDIX II.B

ANNUAL VARIABLE COSTS OF TRANSIT BUS USED 30,000 MILES A YEAR

		Costs by Annual Percent Growth Rates									
		0.0%		1.5%		3.2%		5.0%		10.0%	
YEAR	MILES	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST
1	30000.	23988.	0.7996	24056.	0.8019	24136.	0.8045	24221.	0.8074	24466.	0.8155
2	30000.	19743.	0.7289	20345.	0.7400	21048.	0.7531	21820.	0.7673	24115.	0.8097
3	30000.	17616.	0.6816	18426.	0.6981	19391.	0.7175	20466.	0.7390	23779.	0.8040
4	30000.	14812.	0.6347	15728.	0.6546	16834.	0.6784	18091.	0.7050	22096.	0.7871
5	30000.	11897.	0.5870	12824.	0.6092	13962.	0.6358	15276.	0.6658	19615.	0.7605
6	30000.	11627.	0.5538	12722.	0.5783	14088.	0.6081	15695.	0.6421	21186.	0.7514
7	30000.	9996.	0.5223	11102.	0.5486	12505.	0.5808	14184.	0.6179	20129.	0.7399
8	30000.	9826.	0.4979	11079.	0.5262	12693.	0.5611	14659.	0.6017	21868.	0.7386
9	30000.	12250.	0.4880	14021.	0.5196	16339.	0.5592	19212.	0.6060	30131.	0.7681
10	30000.	10128.	0.4729	11767.	0.5069	13948.	0.5498	16698.	0.6011	27531.	0.7831
11	30000.	9083.	0.4575	10712.	0.4933	12915.	0.5390	15743.	0.5941	27286.	0.7946
12	30000.	9194.	0.4449	11007.	0.4827	13498.	0.5315	16752.	0.5912	30525.	0.8131
13	30000.	9571.	0.4352	11632.	0.4754	14509.	0.5279	18334.	0.5927	35119.	0.8406
14	30000.	10558.	0.4293	13025.	0.4725	16525.	0.5295	21262.	0.6010	42816.	0.8825
15	30000.	11262.	0.4257	14103.	0.4723	18200.	0.5346	23841.	0.6139	50471.	0.9359
16	30000.	12548.	0.4252	15952.	0.4760	20939.	0.5449	27927.	0.6337	62153.	1.0068
17	30000.	14105.	0.4279	18202.	0.4837	24302.	0.5605	33001.	0.6611	77212.	1.0990
18	30000.	13619.	0.4293	17840.	0.4899	24226.	0.5742	33496.	0.6864	82387.	1.1905
19	30000.	14008.	0.4313	18627.	0.4968	25729.	0.5891	36220.	0.7139	93654.	1.2922
20	30000.	15477.	0.4355	20892.	0.5068	29352.	0.6086	42071.	0.7483	114361.	1.4182
SUM =	600000.	261308.		304063.		365137.		448971.		850900.	

APPENDIX II.C

ANNUAL VARIABLE COSTS OF TRANSIT BUS USED 40,000 MILES A YEAR

Costs by Annual Percent Growth Rates

		0.0%		1.5%		3.2%		5.0%		10.0%	
YEAR	MILES	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST
1	40000.	30913.	0.7728	31007.	0.7752	31115.	0.7779	31231.	0.7808	31564.	0.7891
2	40000.	24852.	0.6971	25609.	0.7077	26494.	0.7201	27400.	0.7337	30354.	0.7740
3	40000.	20521.	0.6357	21466.	0.6507	22589.	0.6683	23842.	0.6878	27701.	0.7468
4	40000.	15950.	0.5765	16936.	0.5939	18128.	0.6145	19481.	0.6376	23794.	0.7088
5	40000.	14639.	0.5344	15779.	0.5540	17179.	0.5775	18796.	0.6041	24135.	0.6877
6	40000.	13448.	0.5013	14714.	0.5230	16295.	0.5492	18133.	0.5750	24504.	0.6752
7	40000.	15926.	0.4866	17689.	0.5114	19524.	0.5419	22030.	0.5770	32070.	0.6933
8	40000.	12674.	0.4654	14289.	0.4922	16371.	0.5253	18637.	0.5540	28236.	0.6948
9	40000.	12205.	0.4476	13969.	0.4763	16278.	0.5121	19141.	0.5343	30019.	0.7010
10	40000.	13006.	0.4353	15110.	0.4664	17910.	0.5057	21443.	0.5326	35353.	0.7192
11	40000.	14485.	0.4287	17083.	0.4628	20596.	0.5065	25108.	0.5393	43514.	0.7528
12	40000.	16506.	0.4273	19761.	0.4654	24233.	0.5148	30076.	0.5755	54802.	0.8042
13	40000.	18489.	0.4300	22469.	0.4728	28026.	0.5291	35415.	0.5993	67840.	0.8728
14	40000.	18114.	0.4317	22347.	0.4790	28351.	0.5419	36477.	0.6217	73455.	0.9416
15	40000.	19776.	0.4358	24766.	0.4883	31960.	0.5591	41661.	0.6530	88632.	1.0266
16	40000.	21261.	0.4418	27028.	0.5000	35477.	0.5796	47518.	0.6933	105308.	1.1270
17	40000.	22641.	0.4491	29217.	0.5136	39008.	0.6028	53972.	0.7420	123936.	1.2429
18	40000.	24028.	0.4575	31475.	0.5288	42743.	0.6287	59698.	0.7955	145358.	1.3758
19	40000.	25418.	0.4669	33800.	0.5454	46687.	0.6571	65725.	0.8594	169945.	1.5270
20	40000.	26812.	0.4771	36193.	0.5634	50849.	0.6878	72084.	0.9353	198118.	1.6983
SUM	=800000.	381663.		450709.		550214.		687992.		1358605.	

APPENDIX II.D

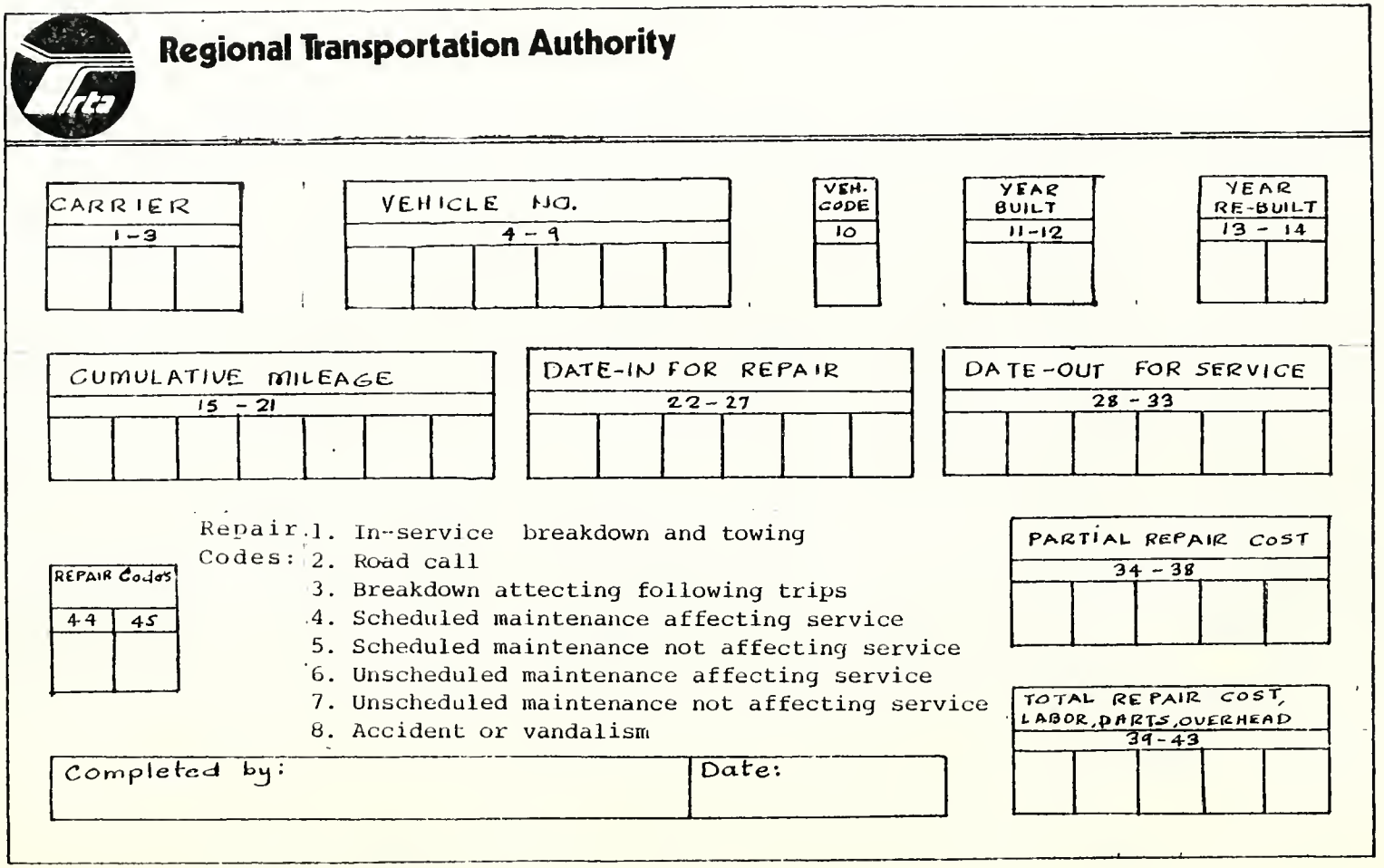
ANNUAL VARIABLE COSTS OF TRANSIT BUS USED DECLINING MILES

Costs by Annual Percent Growth Rates

		0.0%		1.5%		3.2%		5.0%		10.0%	
YEAR	MILES	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST	COST/YR.	AVE.COST
1	50000.	37488.	0.7498	37608.	0.7522	37747.	0.7549	37897.	0.7579	38327.	0.7665
2	40000.	23972.	0.6829	24702.	0.6923	25556.	0.7034	26493.	0.7154	29280.	0.7512
3	40000.	19102.	0.6197	19981.	0.6330	21026.	0.6487	22193.	0.6660	25785.	0.7184
4	40000.	15226.	0.5635	16167.	0.5792	17305.	0.5979	18597.	0.6187	22714.	0.6830
5	40000.	14744.	0.5263	15893.	0.5445	17303.	0.5664	18932.	0.5910	24310.	0.6686
6	30000.	9801.	0.5014	10724.	0.5211	11876.	0.5451	13230.	0.5723	17859.	0.6595
7	30000.	12155.	0.4907	13501.	0.5132	15207.	0.5408	17249.	0.5726	24478.	0.6769
8	30000.	10103.	0.4753	11391.	0.4999	13051.	0.5302	15072.	0.5655	22485.	0.6841
9	25000.	7686.	0.4624	8797.	0.4885	10251.	0.5210	12054.	0.5591	18904.	0.6897
10	25000.	7501.	0.4508	8715.	0.4785	10330.	0.5133	12368.	0.5545	20391.	0.6987
11	20000.	6115.	0.4430	7211.	0.4721	8694.	0.5090	10598.	0.5532	18369.	0.7105
12	20000.	6501.	0.4369	7783.	0.4679	9545.	0.5074	11846.	0.5552	21584.	0.7294
13	20000.	6787.	0.4321	8249.	0.4652	10289.	0.5078	13001.	0.5598	24904.	0.7546
14	20000.	7230.	0.4289	8920.	0.4643	11316.	0.5105	14560.	0.5676	29320.	0.7877
15	20000.	7795.	0.4271	9761.	0.4653	12596.	0.5158	16501.	0.5791	34932.	0.8303
16	10000.	4079.	0.4267	5186.	0.4665	6807.	0.5193	9079.	0.5862	20205.	0.8562
17	10000.	4207.	0.4266	5429.	0.4681	7248.	0.5237	9842.	0.5947	23027.	0.8870
18	10000.	4302.	0.4267	5636.	0.4701	7654.	0.5288	10582.	0.6044	26028.	0.9227
19	10000.	4459.	0.4270	5929.	0.4726	8190.	0.5347	11529.	0.6156	29811.	0.9647
20	10000.	4648.	0.4278	6274.	0.4757	8815.	0.5416	12635.	0.6285	34345.	1.0141
SUM =	500000.										

APPENDIX III

SUBURBAN LOCOMOTIVE MAINTENANCE SURVEY FORM



8/4/2008
WT 140786 1 63 00
HF GROUP – IN